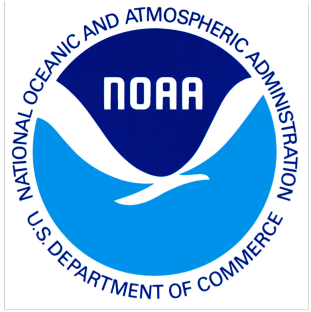
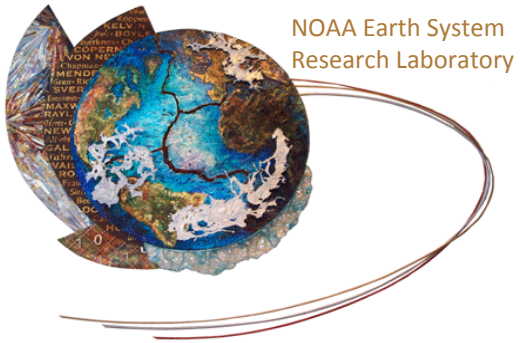




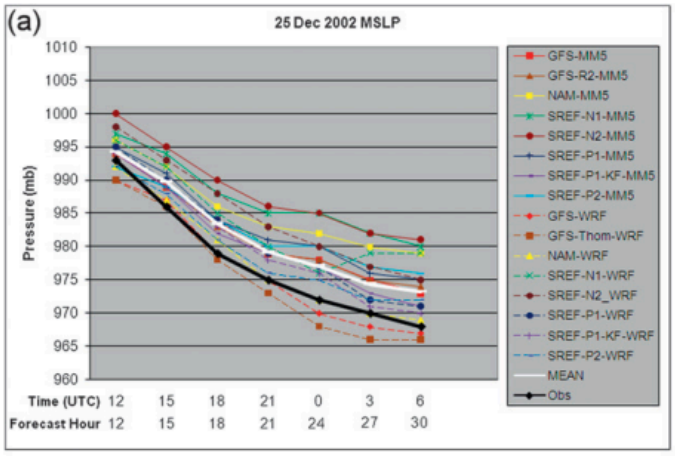
Ensemble prediction and winter weather
(with some attention to Sandy)

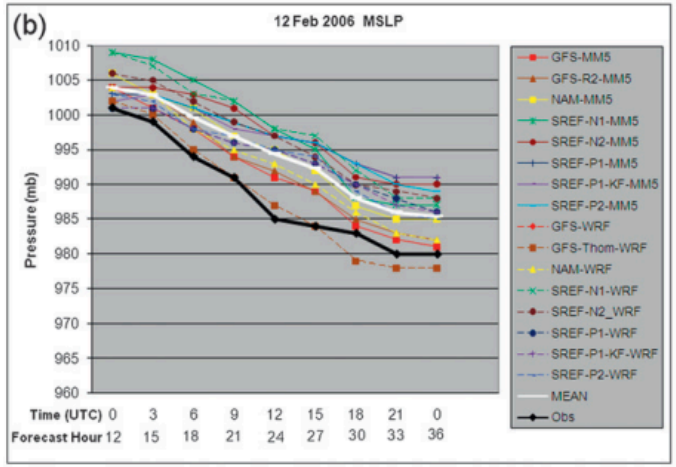
Tom Hamill
NOAA Earth System Research Lab
tom.hamill@noaa.gov
(303) 497-3060

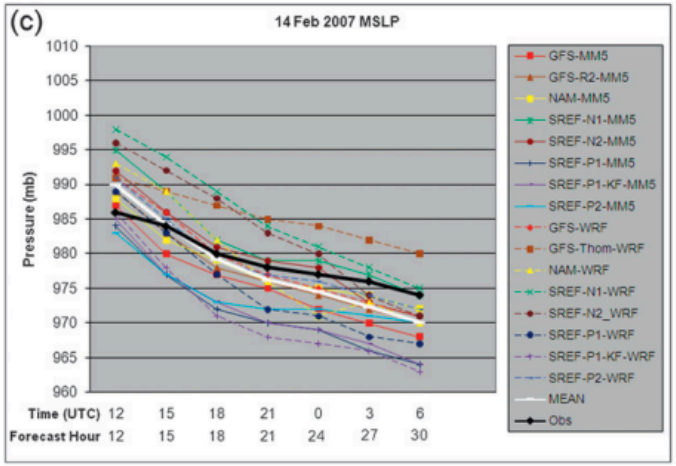
Organization of this talk.

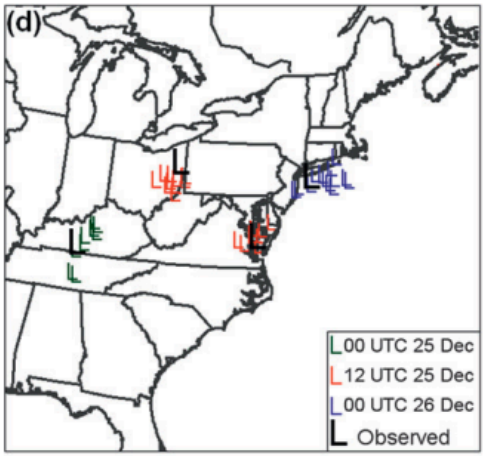
- Part 1: Ensemble theory and nuts and bolts.
  - Motivation for ensembles
  - How we construct them.
  - Advantages/disadvantages of some various ensemble approaches.

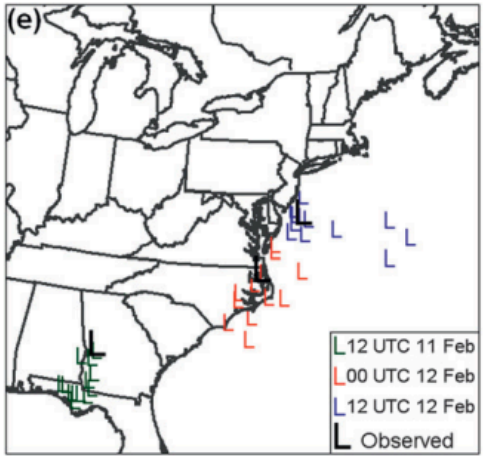
- Part 2: Using ensembles for winter weather.

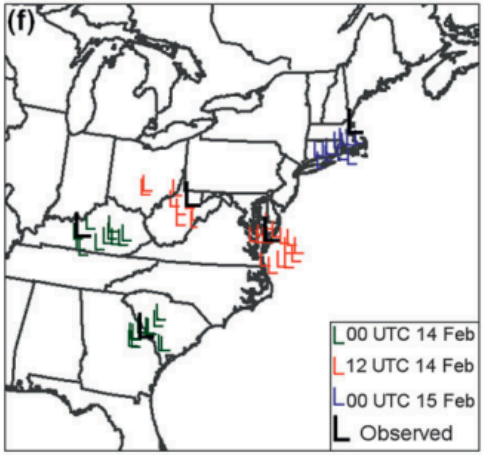










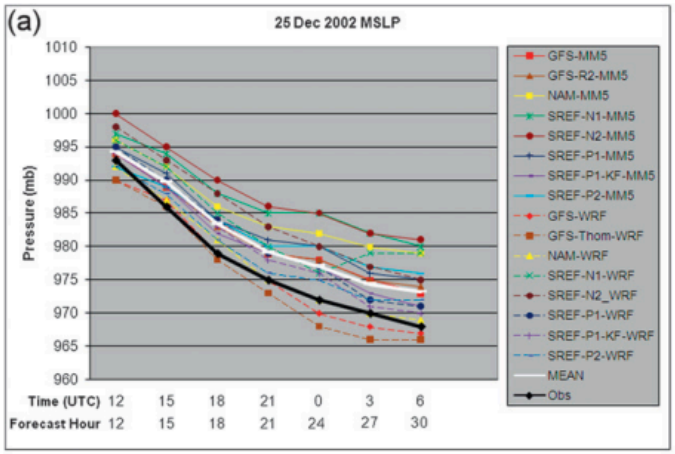


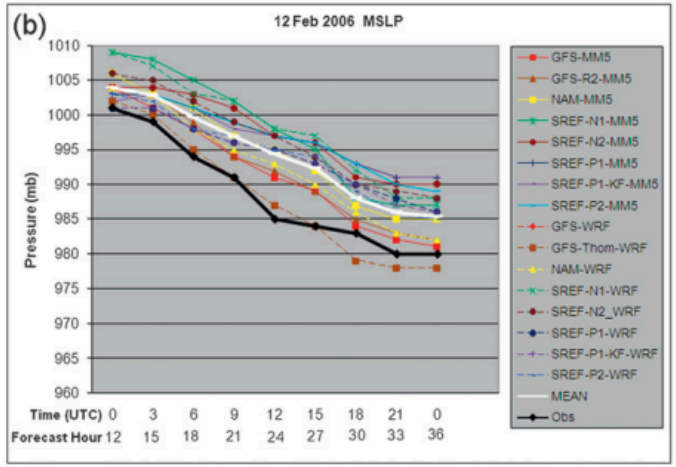
Reminder: ensemble guidance provides you with (probably) a lower bound for the forecast uncertainty.

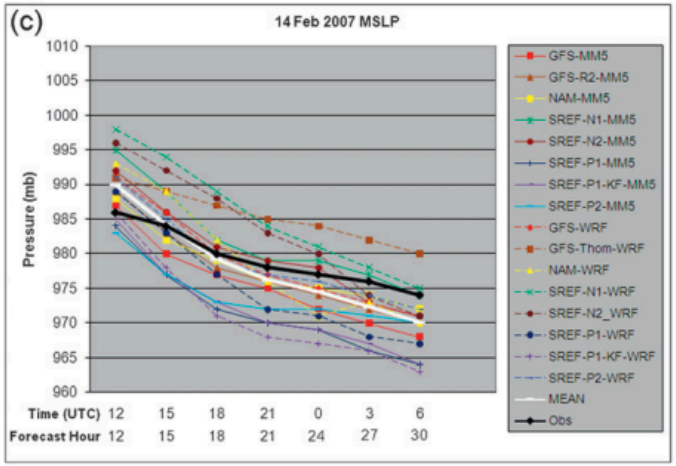
One of the more dangerous practices is to assume a high level of confidence based on a low spread in the ensemble.

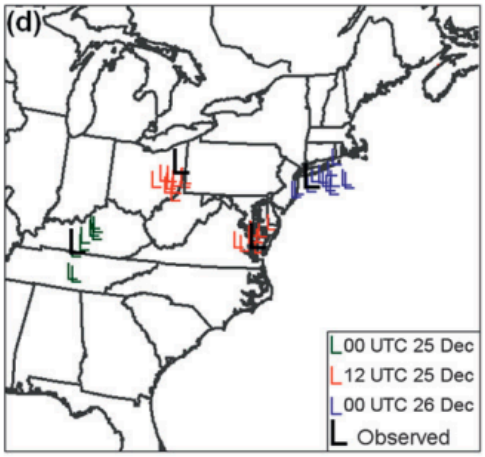
This will be (and is) getting less and less true with each passing year.

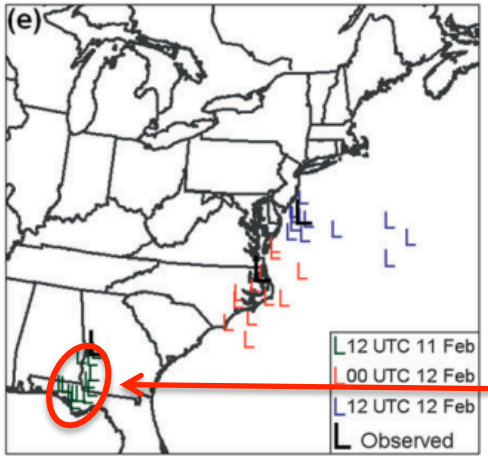
Novak and Colle, WAF June 2012

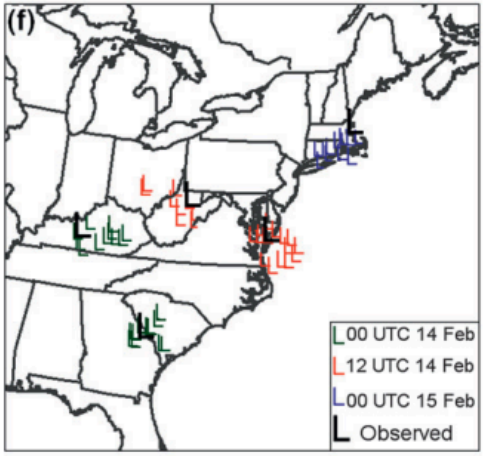












Observed was out of the range of the ensemble

Novak and Colle, WAF June 2012

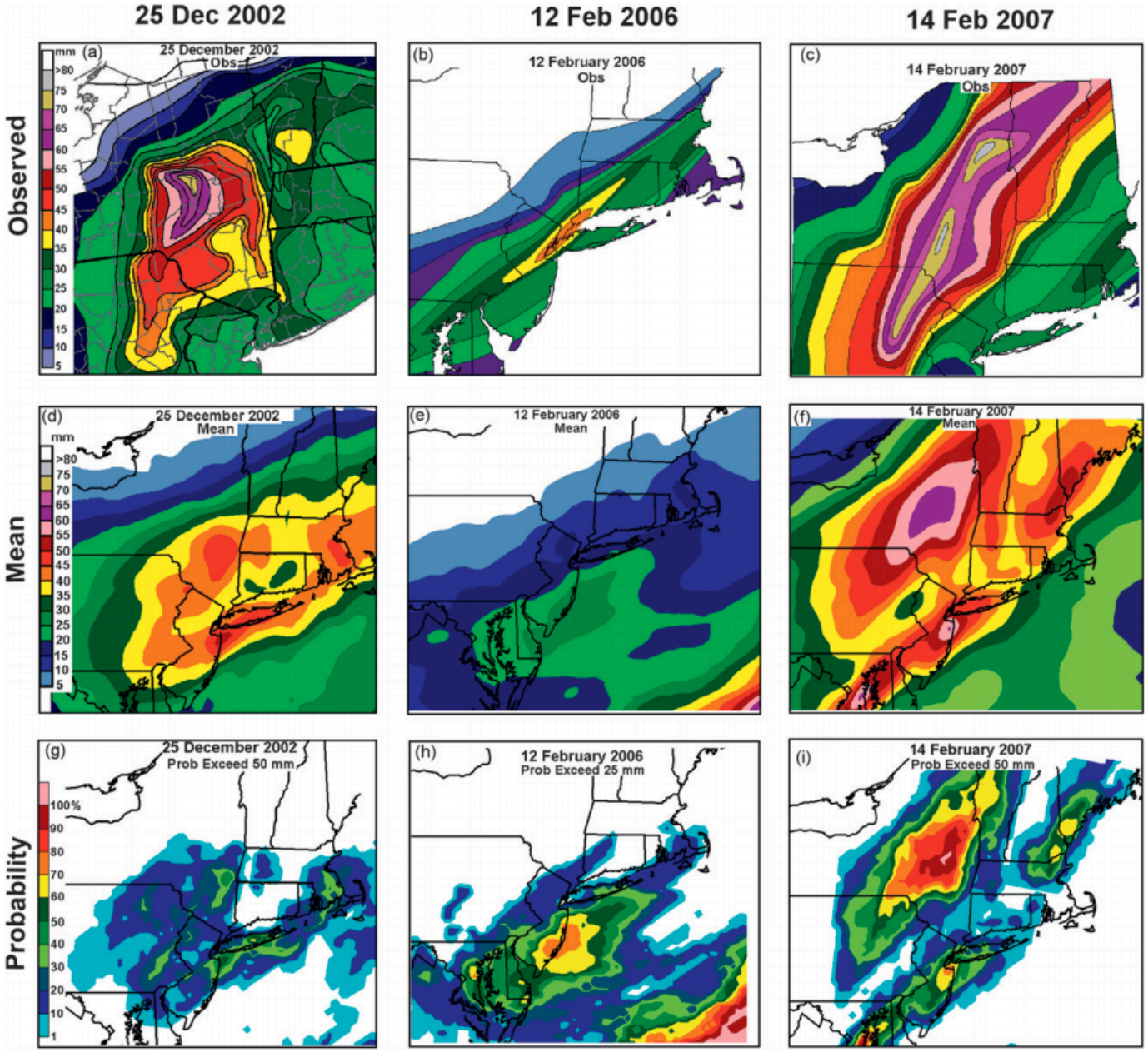


FIG. 2. (a)–(c) Manually analyzed cooperative observer storm total liquid equivalent precipitation (mm, shaded every 5 mm according to scale) for the (a) 25 Dec 2002, (b) 12 Feb 2006, and (c) 14 Feb 2007 cases. (d)–(f) Corresponding ensemble mean forecast storm total precipitation. (g)–(i) Corresponding ensemble probability (%) of exceeding 50, 25, and 50 mm for the 25 Dec 2002, 12 Feb 2006, and 14 Feb 2007 cases, respectively.

Snowfall with three winter storms and SREF forecasts.

ref: ibid.

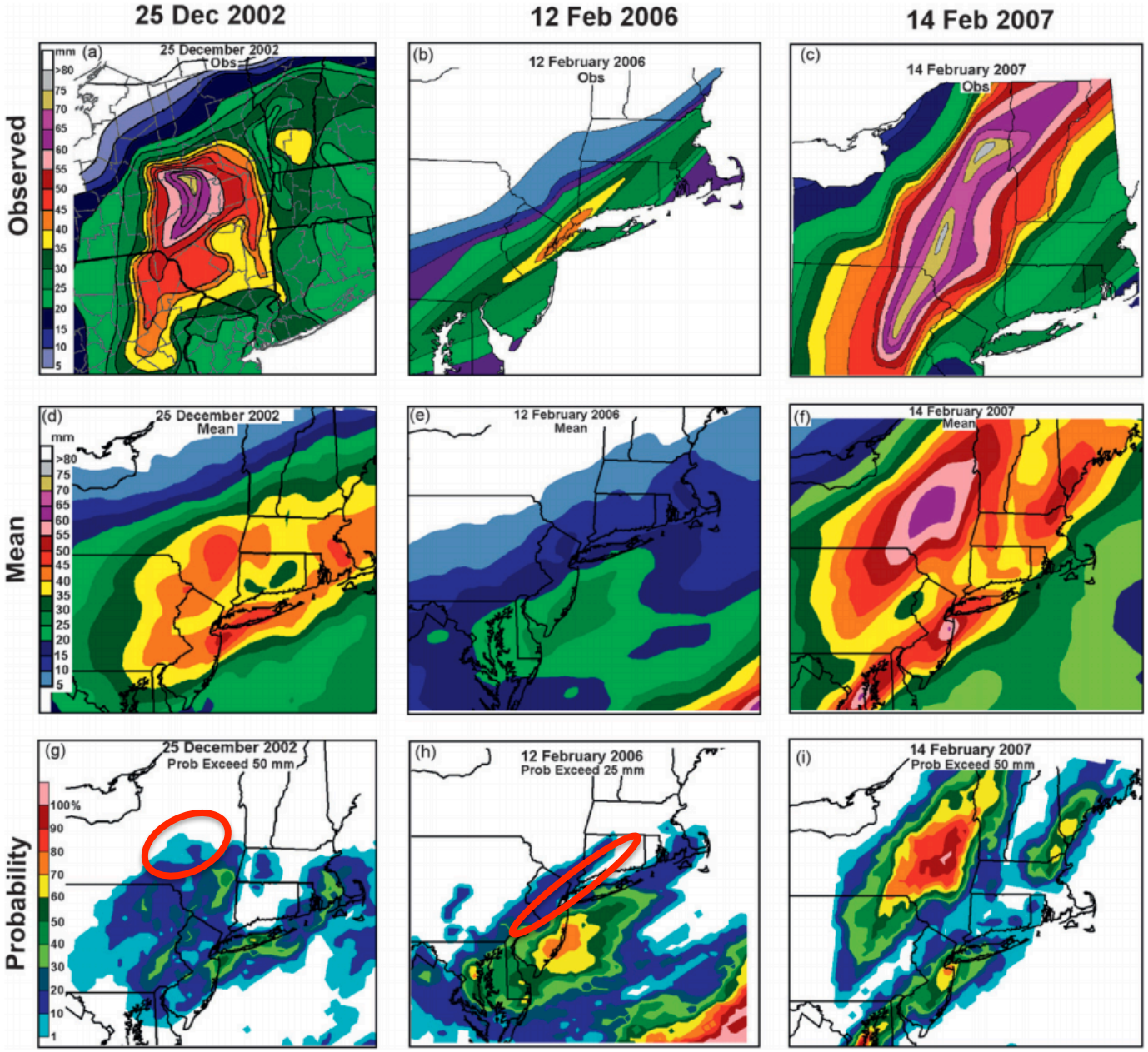


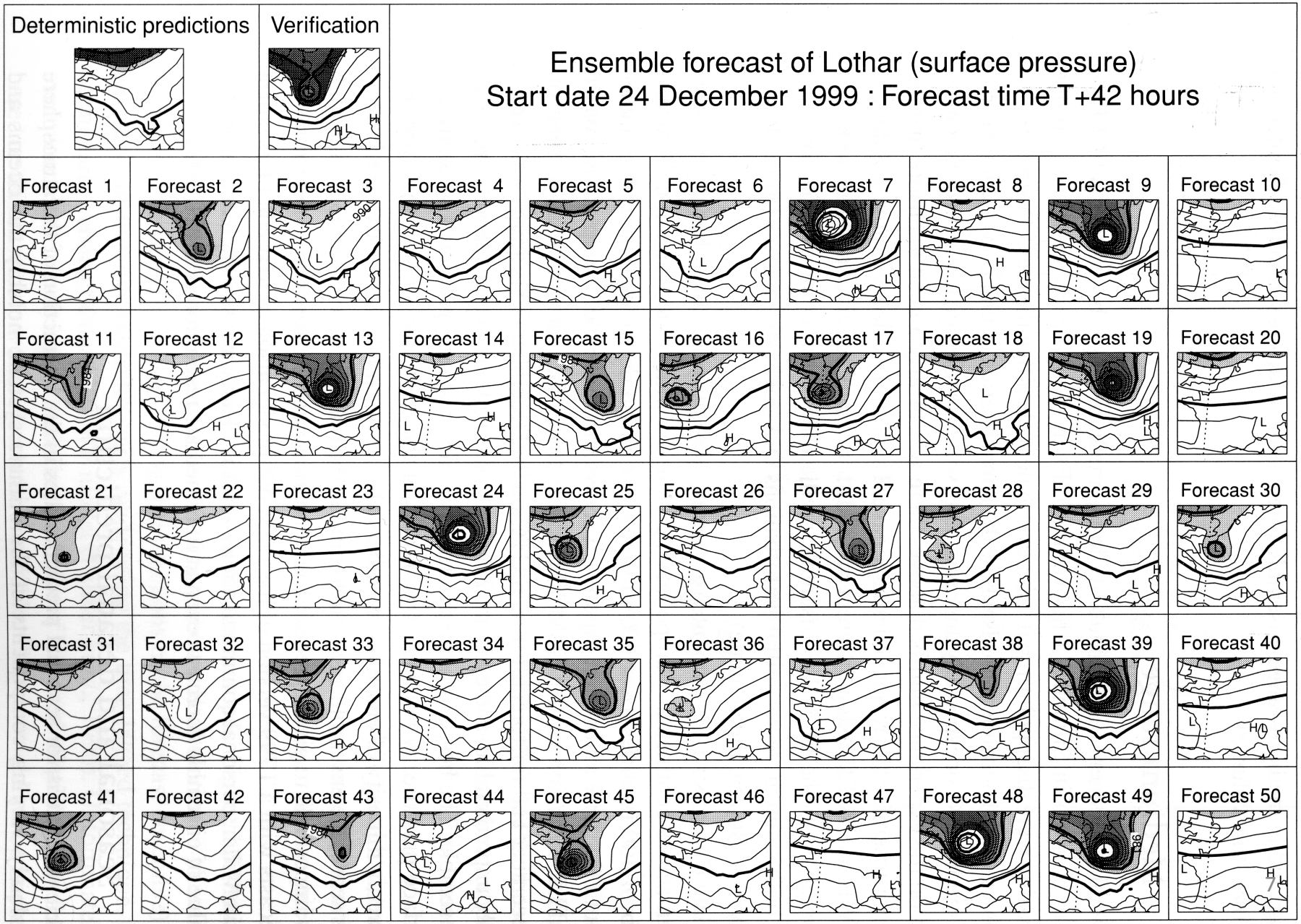
FIG. 2. (a)–(c) Manually analyzed cooperative observer storm total liquid equivalent precipitation (mm, shaded every 5 mm according to scale) for the (a) 25 Dec 2002, (b) 12 Feb 2006, and (c) 14 Feb 2007 cases. (d)–(f) Corresponding ensemble mean forecast storm total precipitation. (g)–(i) Corresponding ensemble probability (%) of exceeding 50, 25, and 50 mm for the 25 Dec 2002, 12 Feb 2006, and 14 Feb 2007 cases, respectively.

Snowfall with three winter storms and SREF forecasts.

Probabilities for the heaviest snow regions were not well forecast in two of these three storm.

ref: ibid.

“Stamp maps”


Deterministic predictions
Verification
Ensemble forecast of Lothar (surface pressure)
Start date 24 December 1999 : Forecast time T+42 hours
Forecast 1
Forecast 2
Forecast 3
Forecast 4
Forecast 5
Forecast 6
Forecast 7
Forecast 8
Forecast 9
Forecast 10
Forecast 11
Forecast 12
Forecast 13
Forecast 14
Forecast 15
Forecast 16
Forecast 17
Forecast 18
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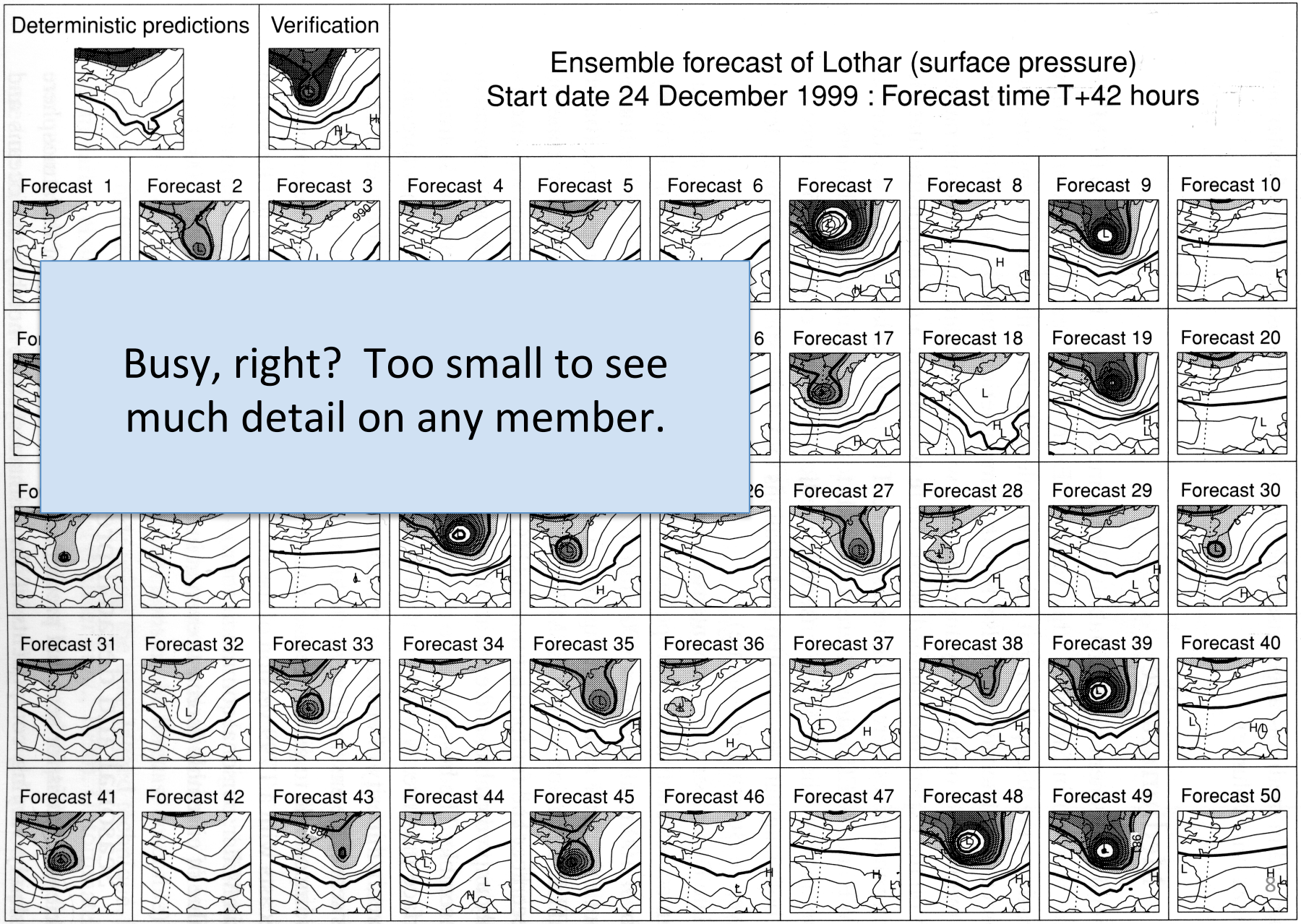
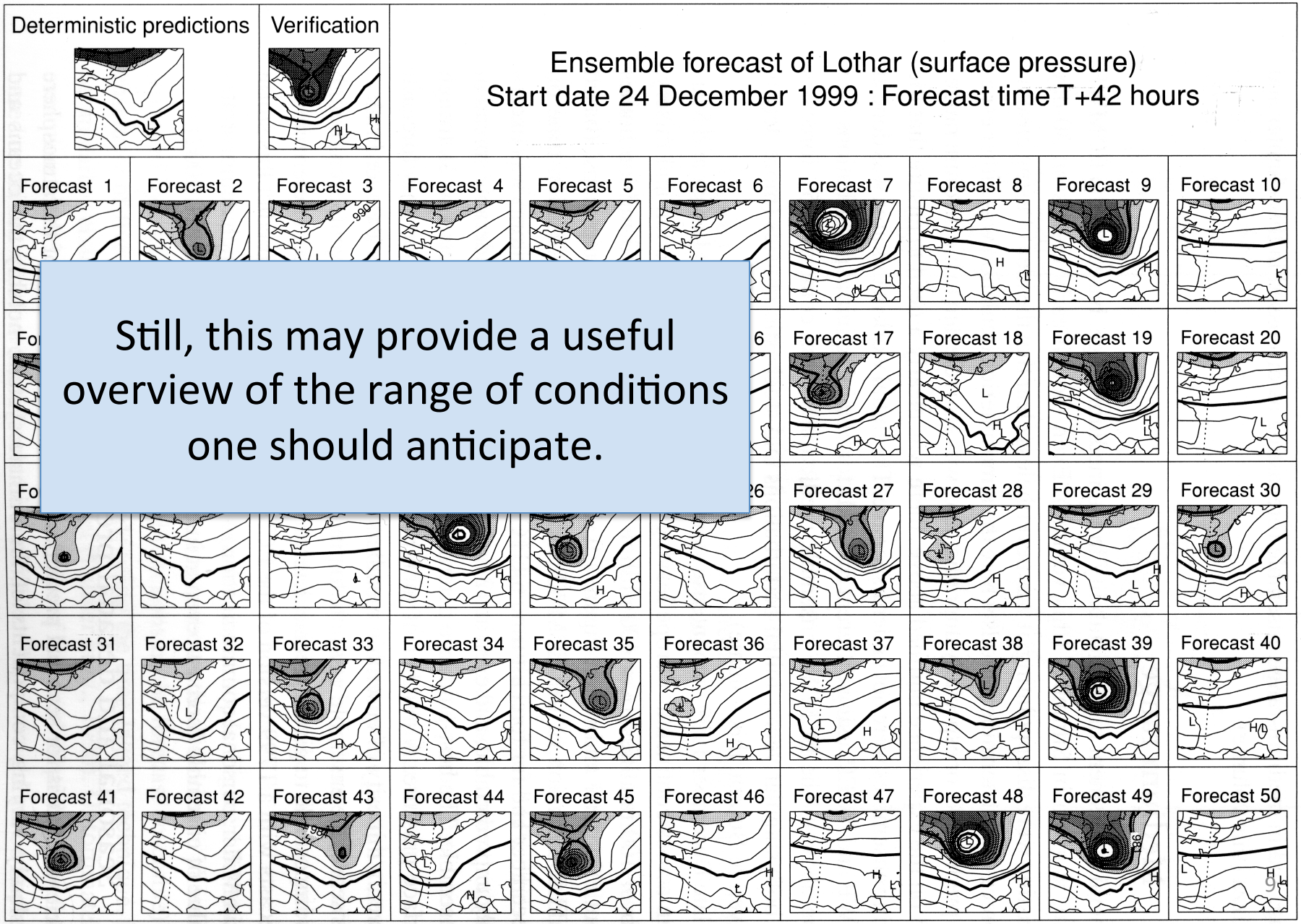
Forecast 48
Forecast 49
Forecast 50

“Stamp maps”



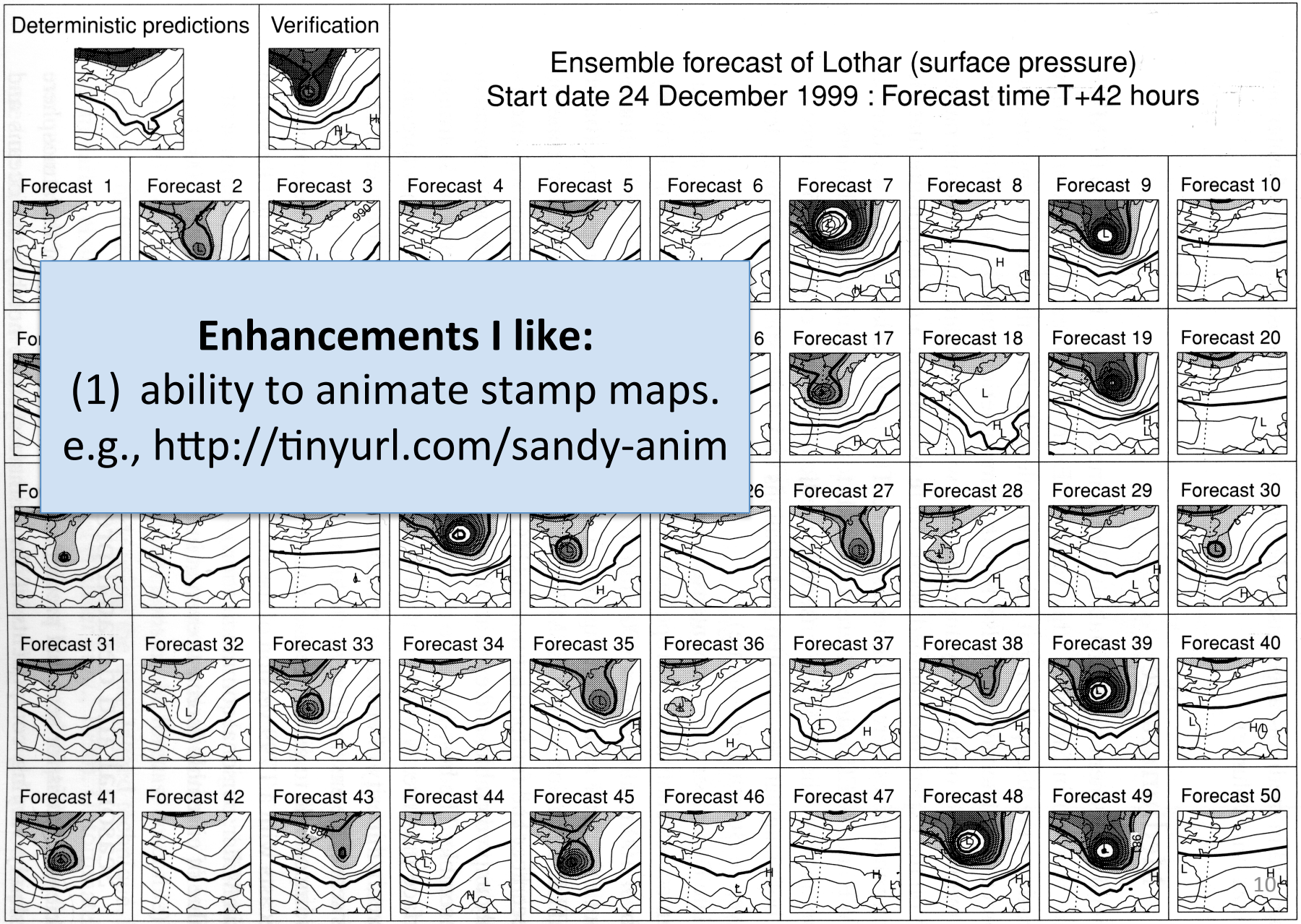
Busy, right? Too small to see much detail on any member.

“Stamp maps”



Still, this may provide a useful overview of the range of conditions one should anticipate.

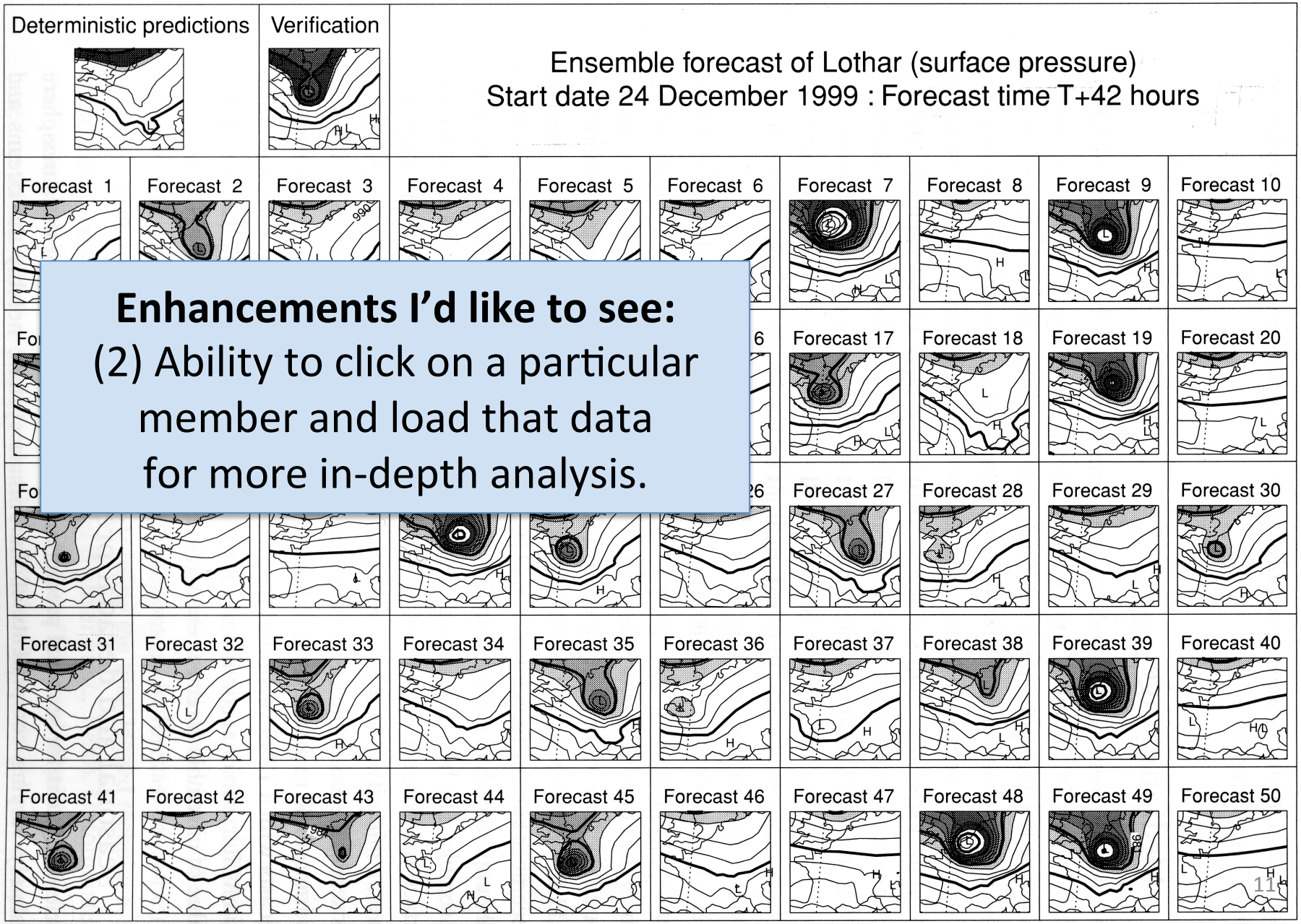
“Stamp maps”



Enhancements I like:

(1) ability to animate stamp maps.
e.g., http://tinyurl.com/sandy-anim

“Stamp maps”

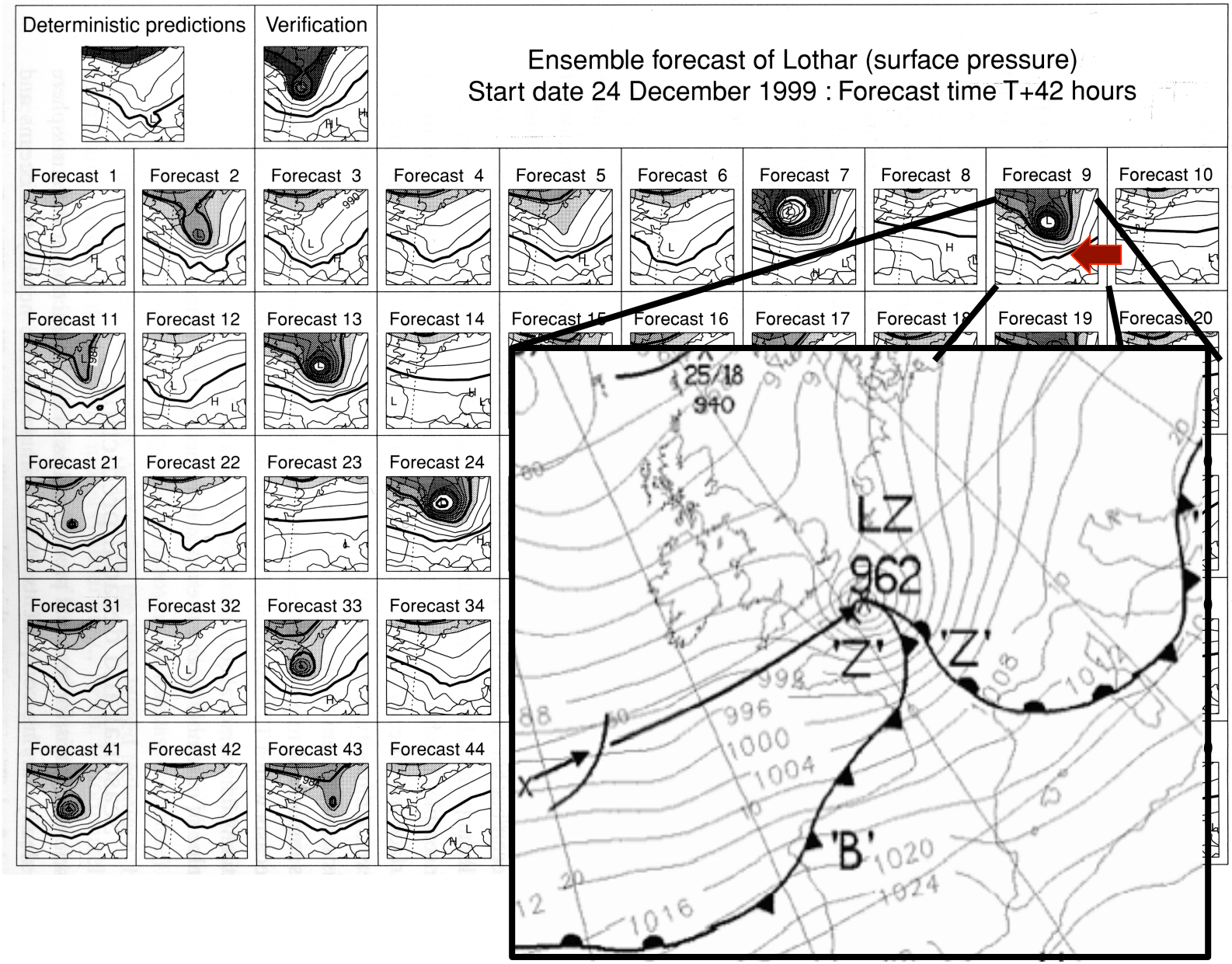


Enhancements I’d like to see:

(2) Ability to click on a particular member and load that data for more in-depth analysis.

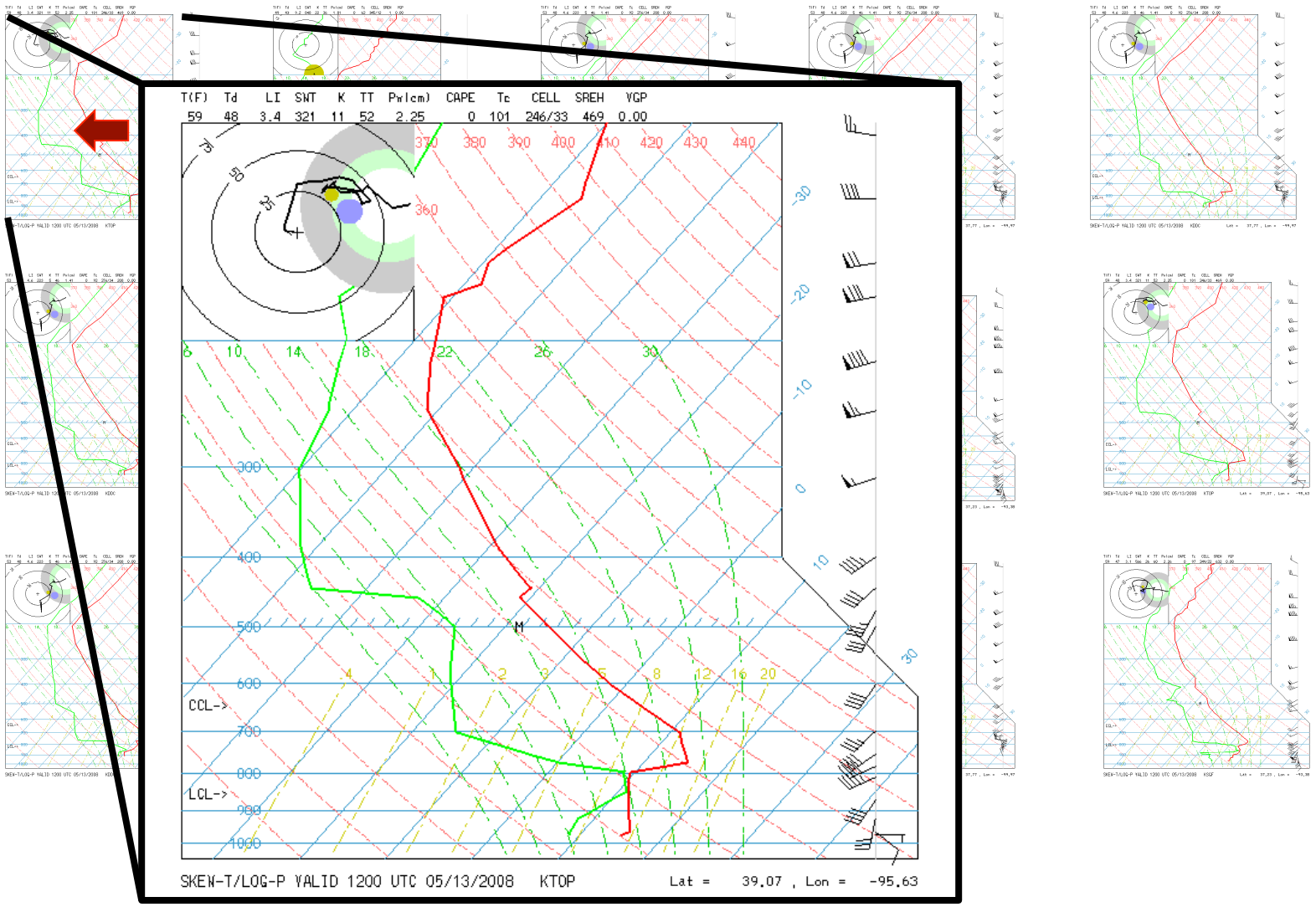
Stamp maps

Zoom capability with mouse over event



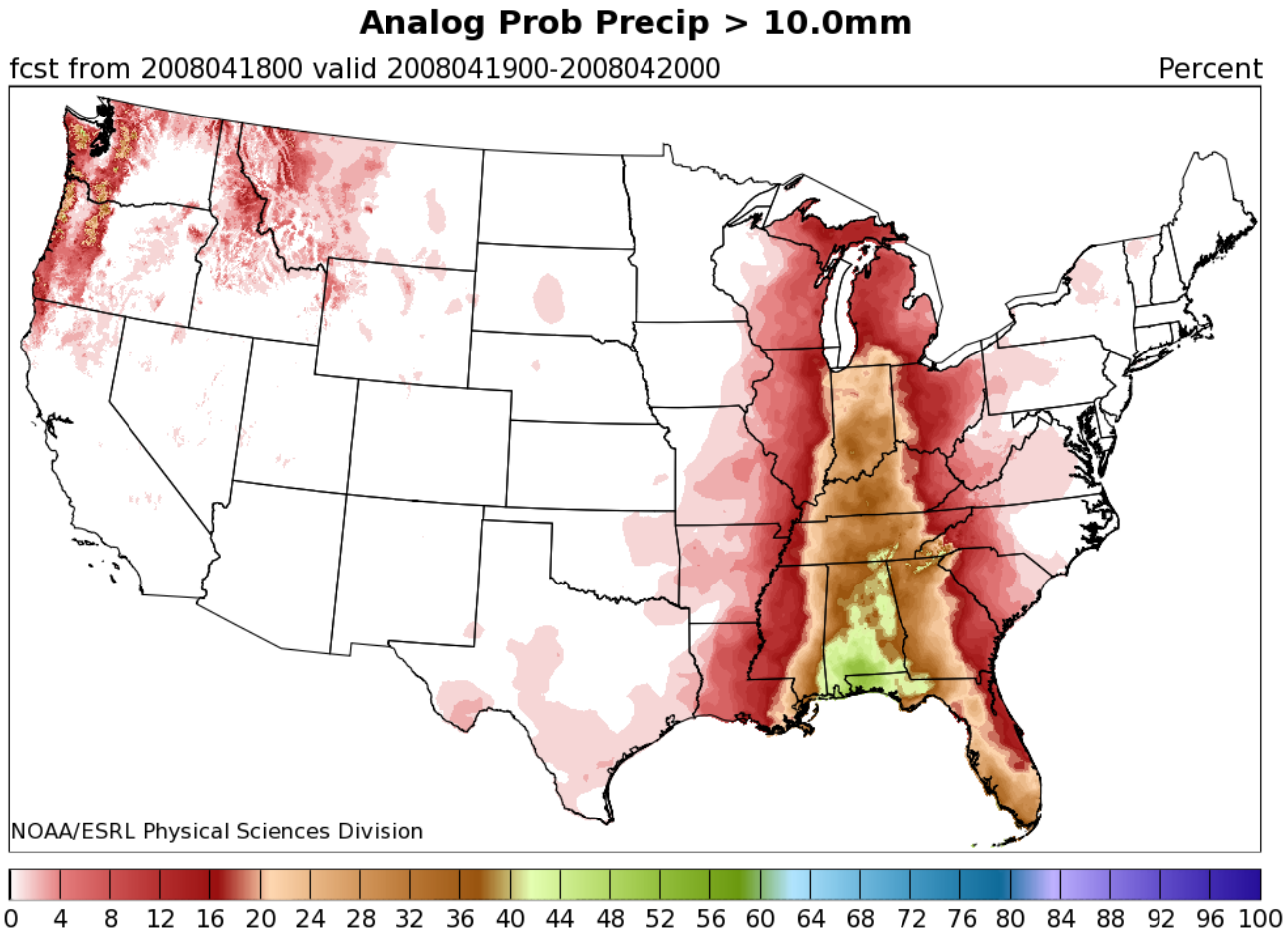
from Tim Palmer's book chapter, 2006, in "*Predictability of Weather and Climate*".

Stamp Skew-T's with mouse-over



Probability plots

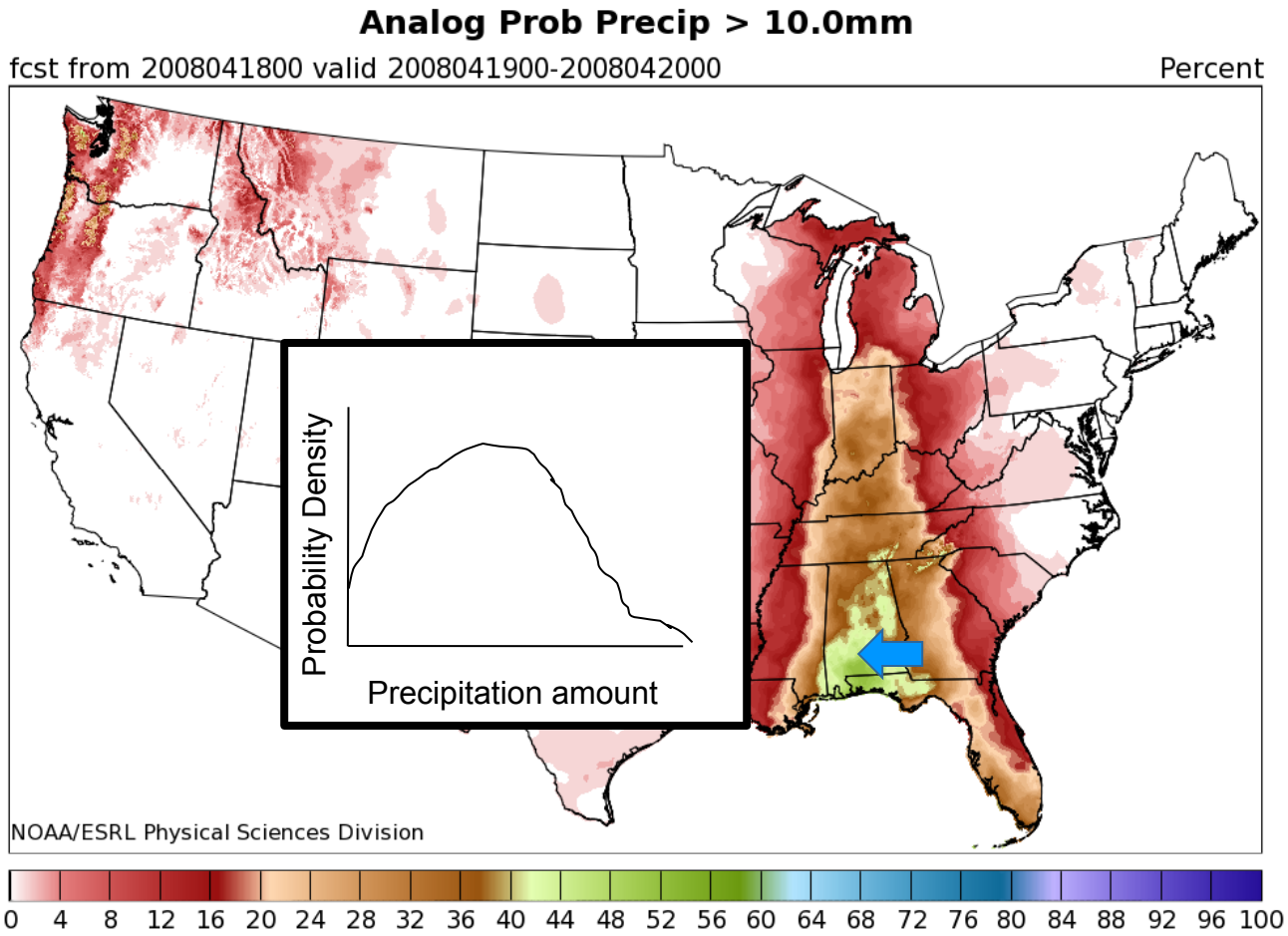
- Provides a graphical display of probabilities for a particular event, here for probability of greater than 10 mm rainfall in 24 h.
- Advantage: simple, relatively intuitive.
- Disadvantages: no sense of the meteorology involved, doesn't provide information on whole pdf.



from Hamill & Whitaker's analog reforecast technique web page, www.cdc.noaa.gov/reforecast/narr.

Probability plots

- With mouse-over event capability

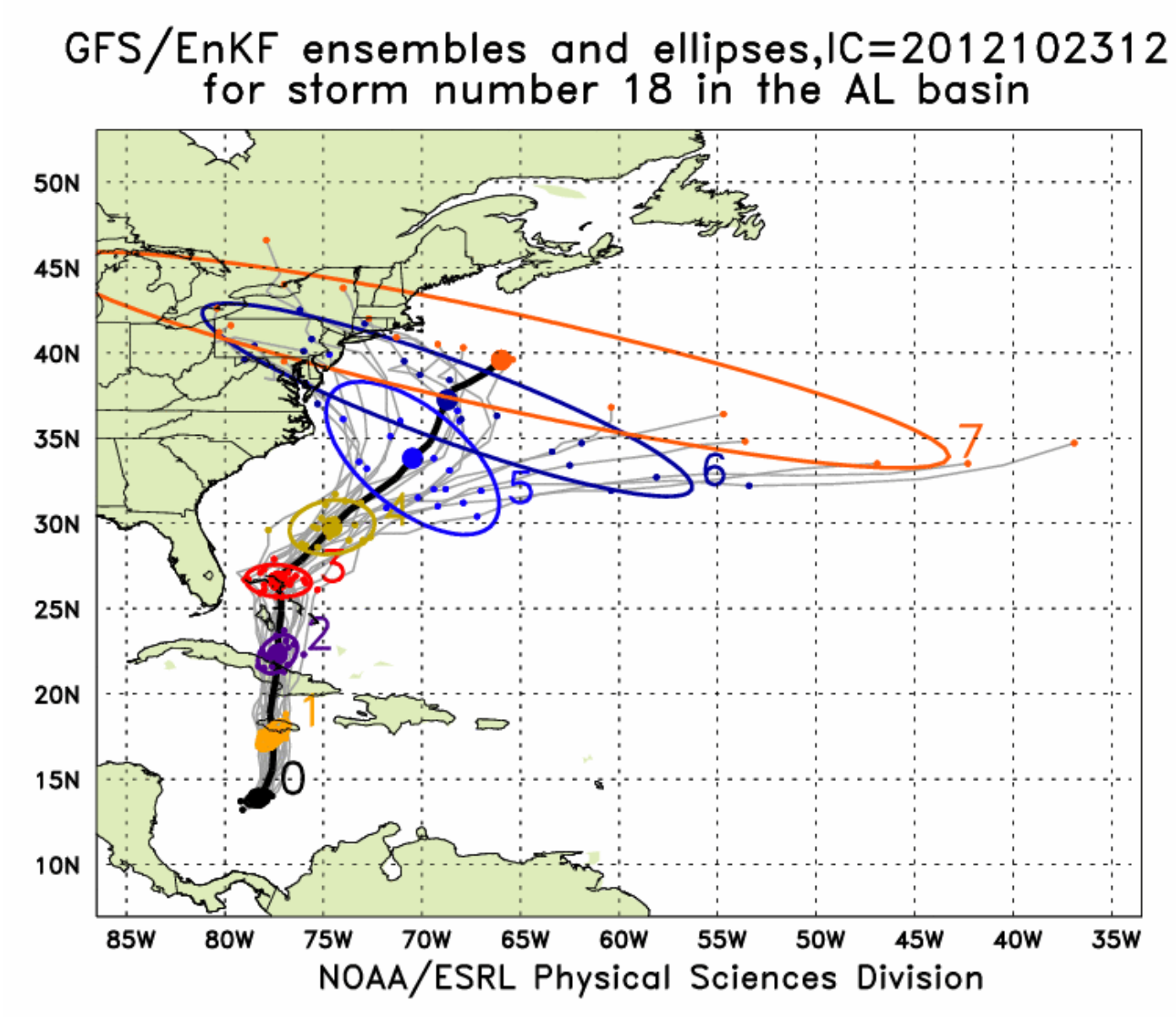


from Hamill & Whitaker's analog reforecast technique web page, www.cdc.noaa.gov/reforecast/narr.

Hurricane Sandy

"Sandy, you hurt me **real bad**"

Hurricane Sandy

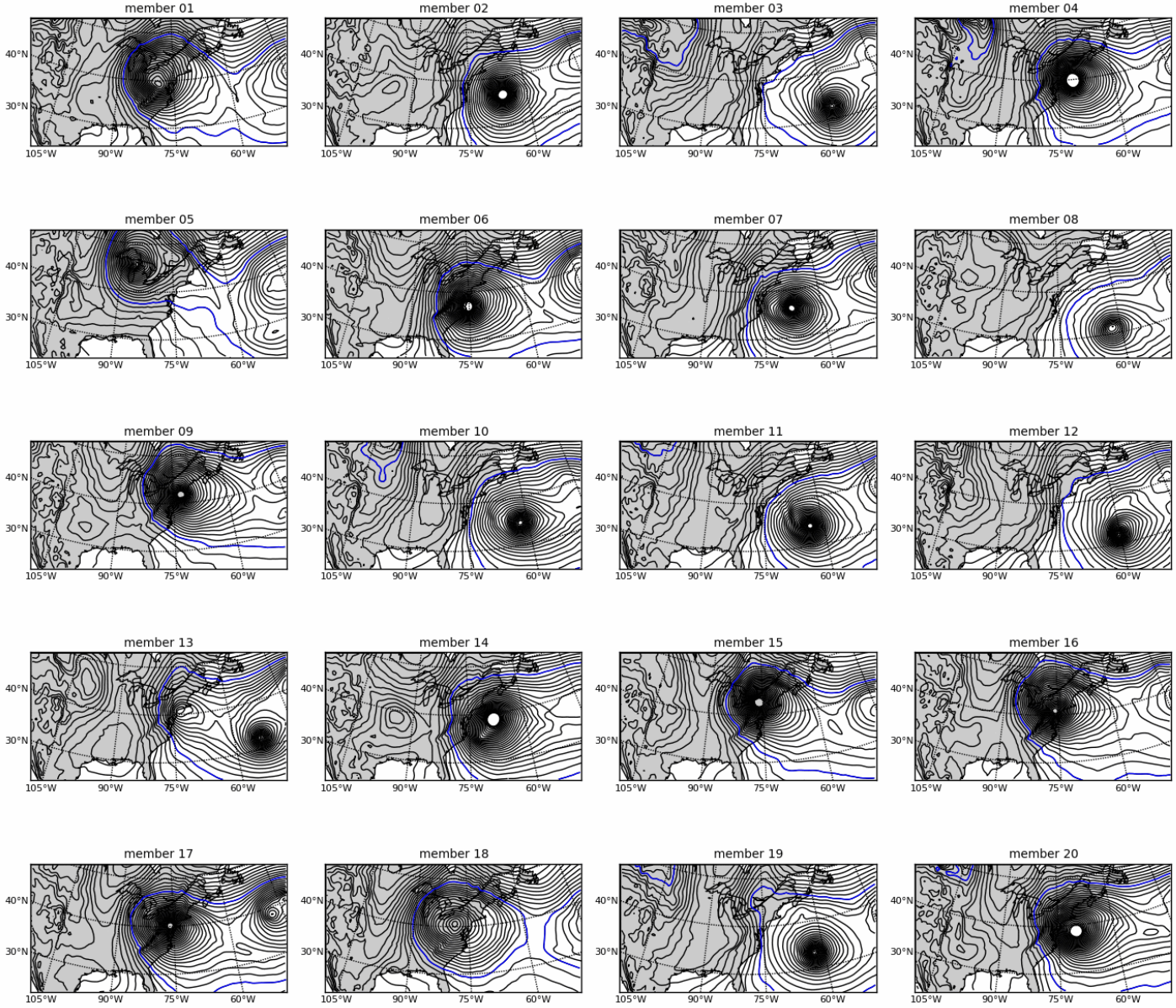


at this lead, ~6 days prior to the landfall, there was tremendous uncertainty as to the track of Sandy.

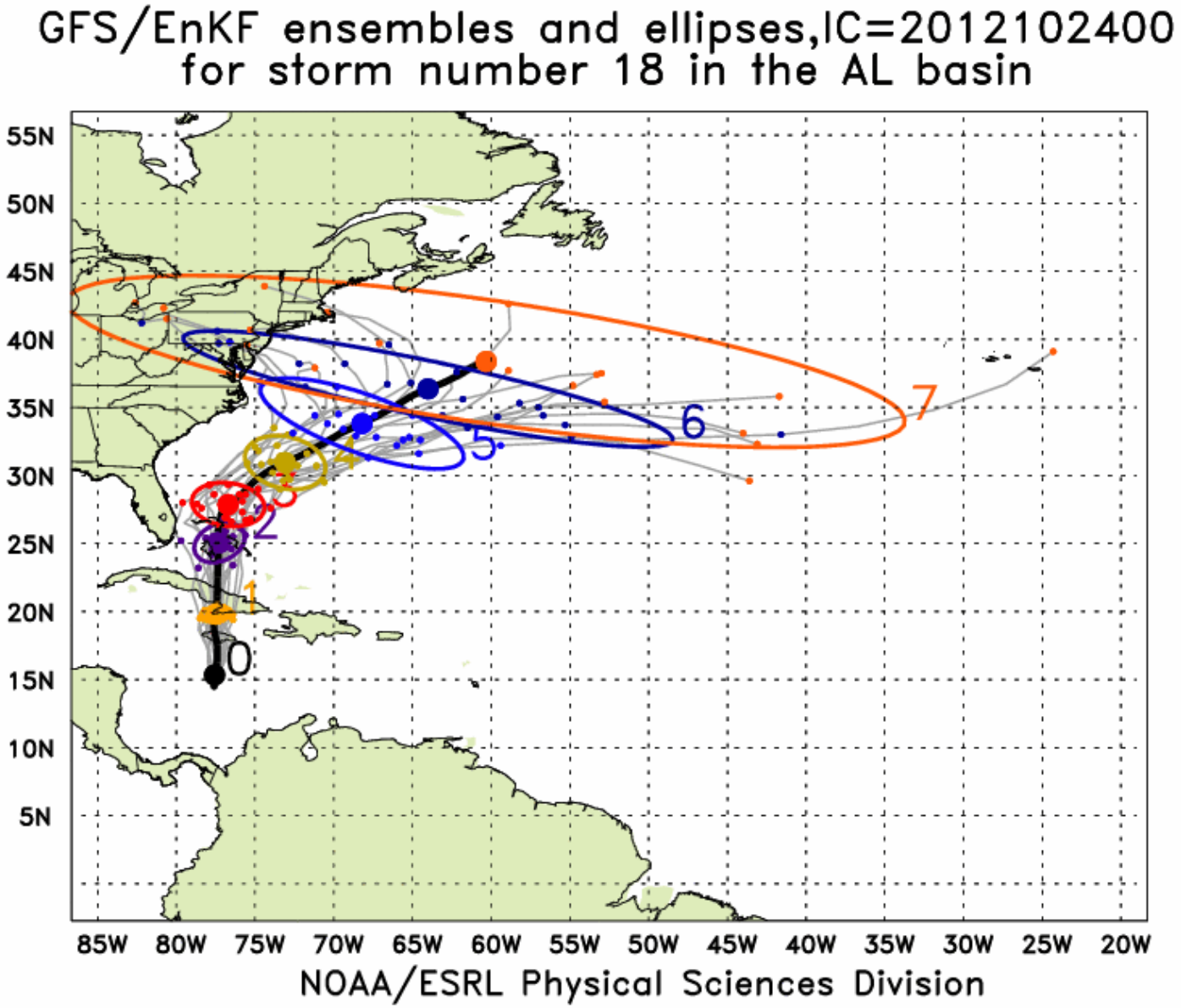
Plots like these could be done for winter storm tracks, too.

T382 GFS/EnKF MSLP ens 144-hr fcst for 18L from 2012102312

+ 6 day forecast stamp maps of MSLP

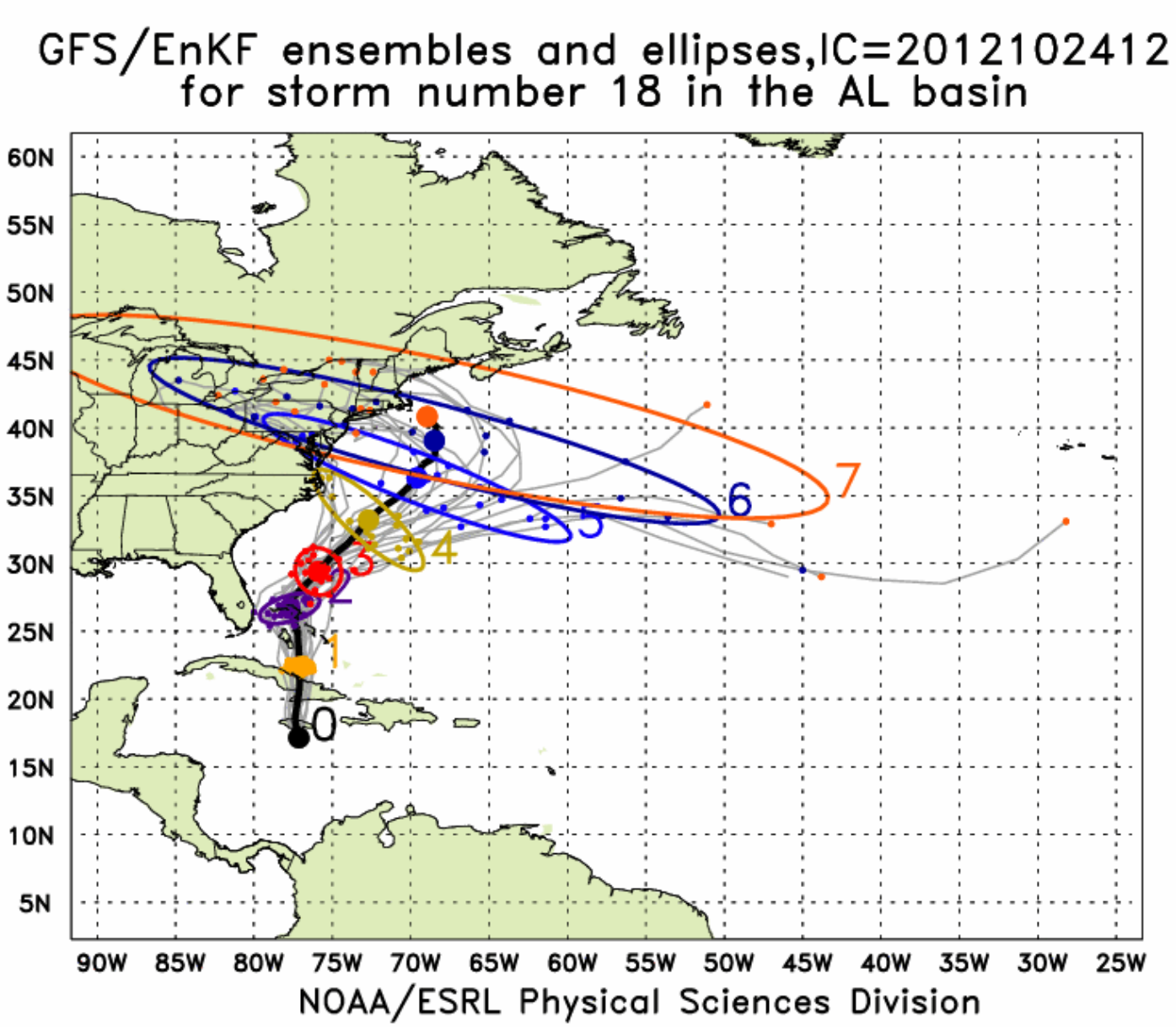


Hurricane Sandy



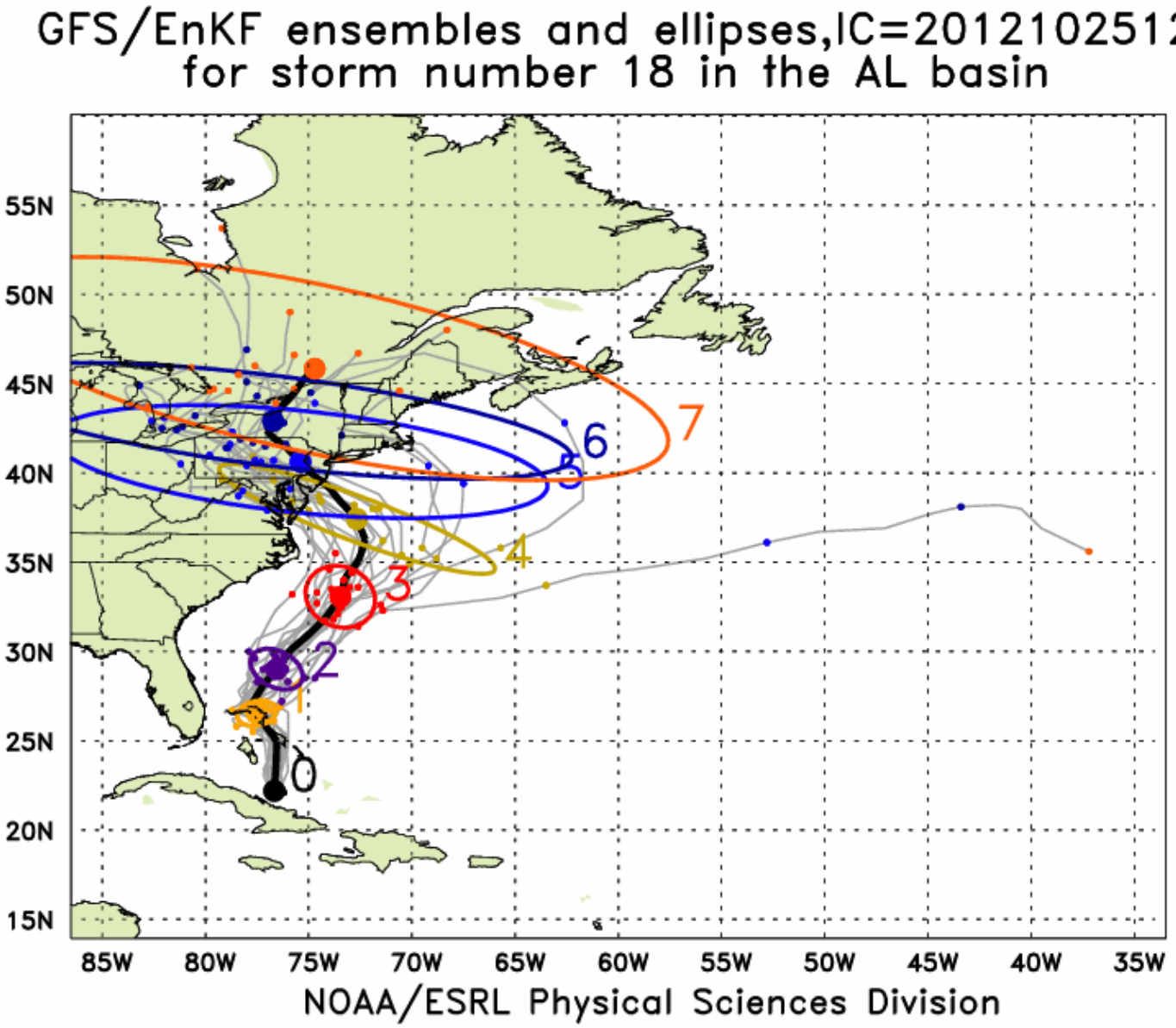
at this lead, ~ 5.5 days prior to the landfall, there was tremendous uncertainty as to the track of Sandy.

Hurricane Sandy



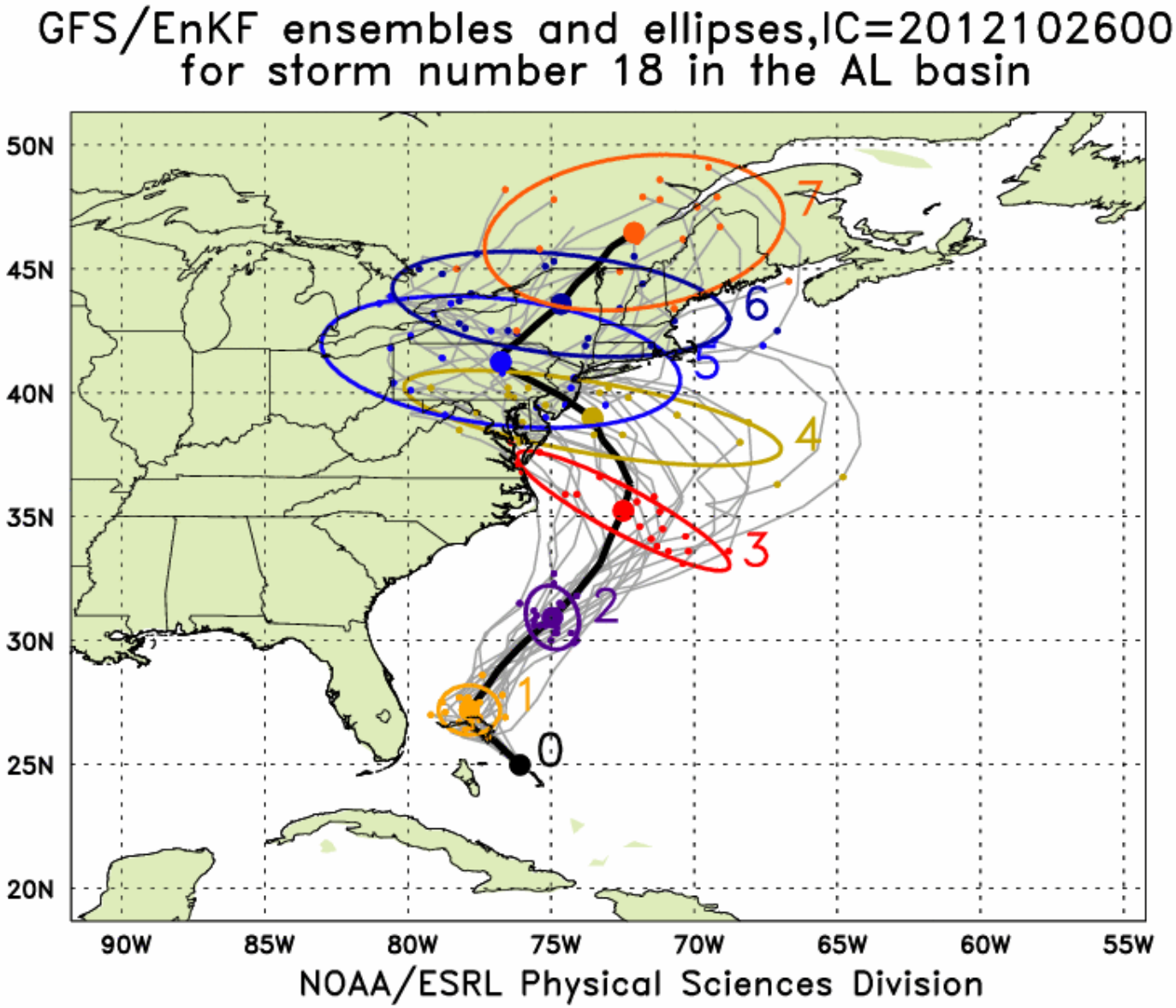
at this lead, ~ 5.0 days prior to the landfall, there was tremendous uncertainty as to the track of Sandy.

Hurricane Sandy

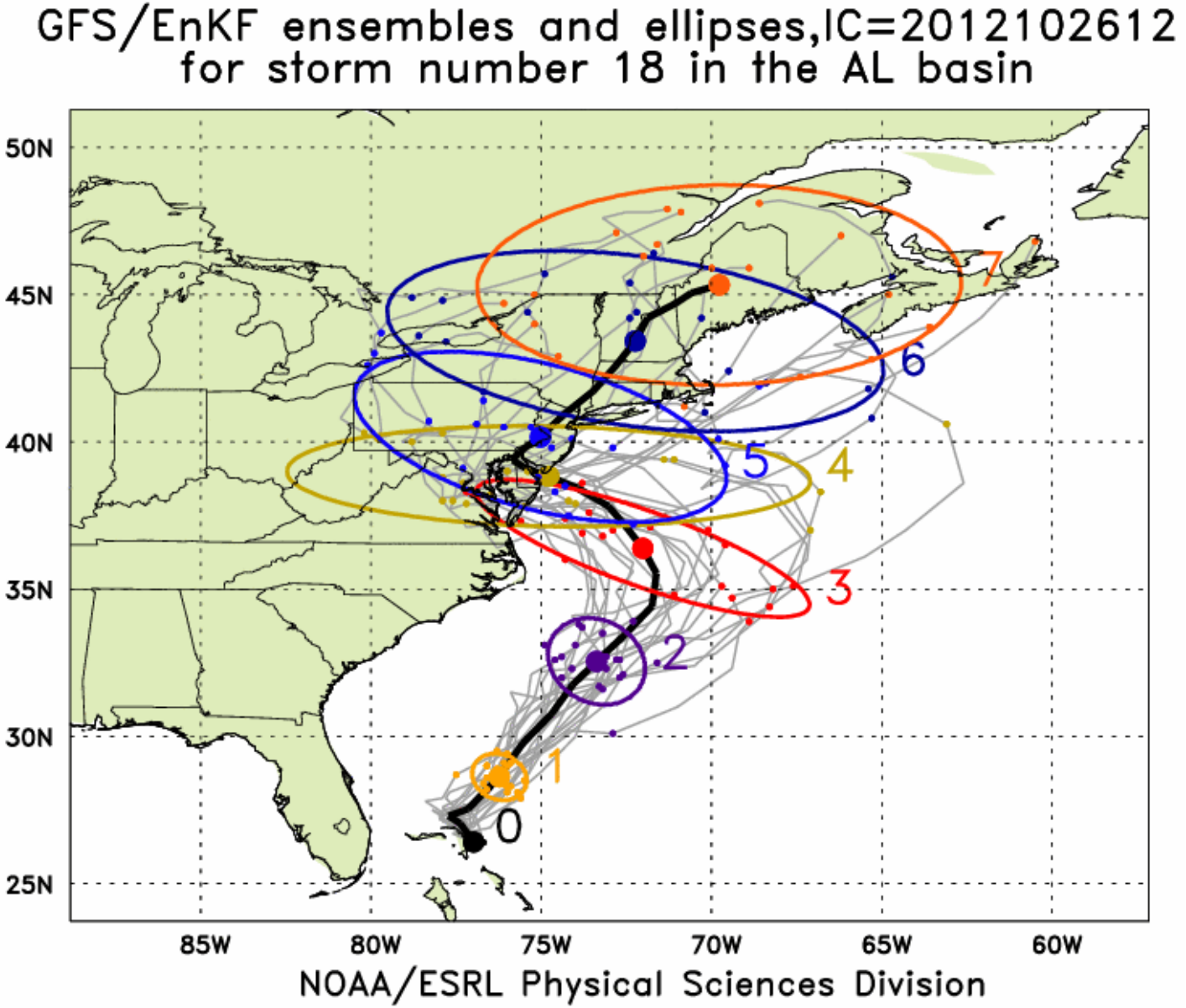


at this lead, ~ 4.5 days prior to the landfall, finally a reduction in uncertainty as to the track of Sandy.

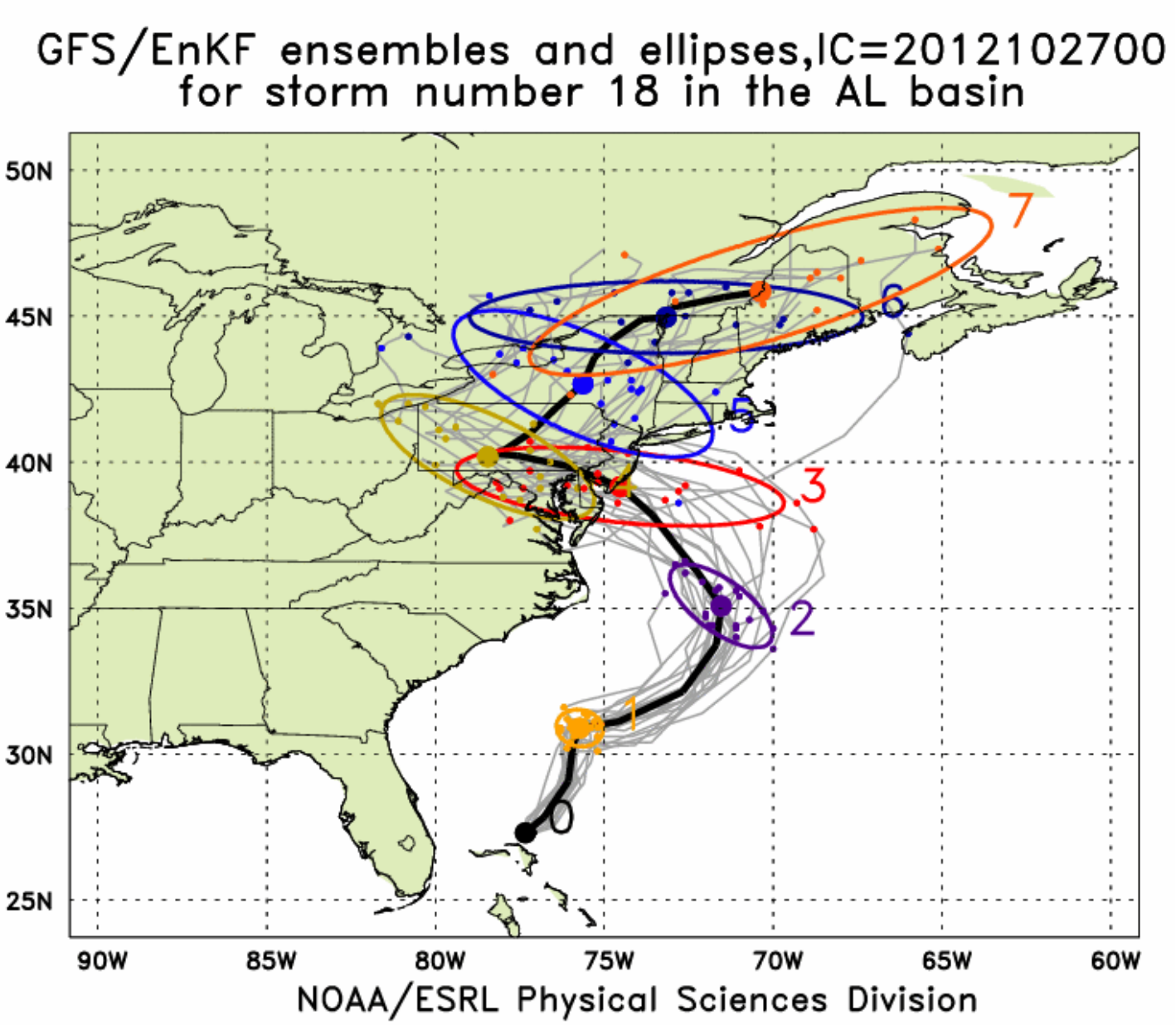
Hurricane Sandy



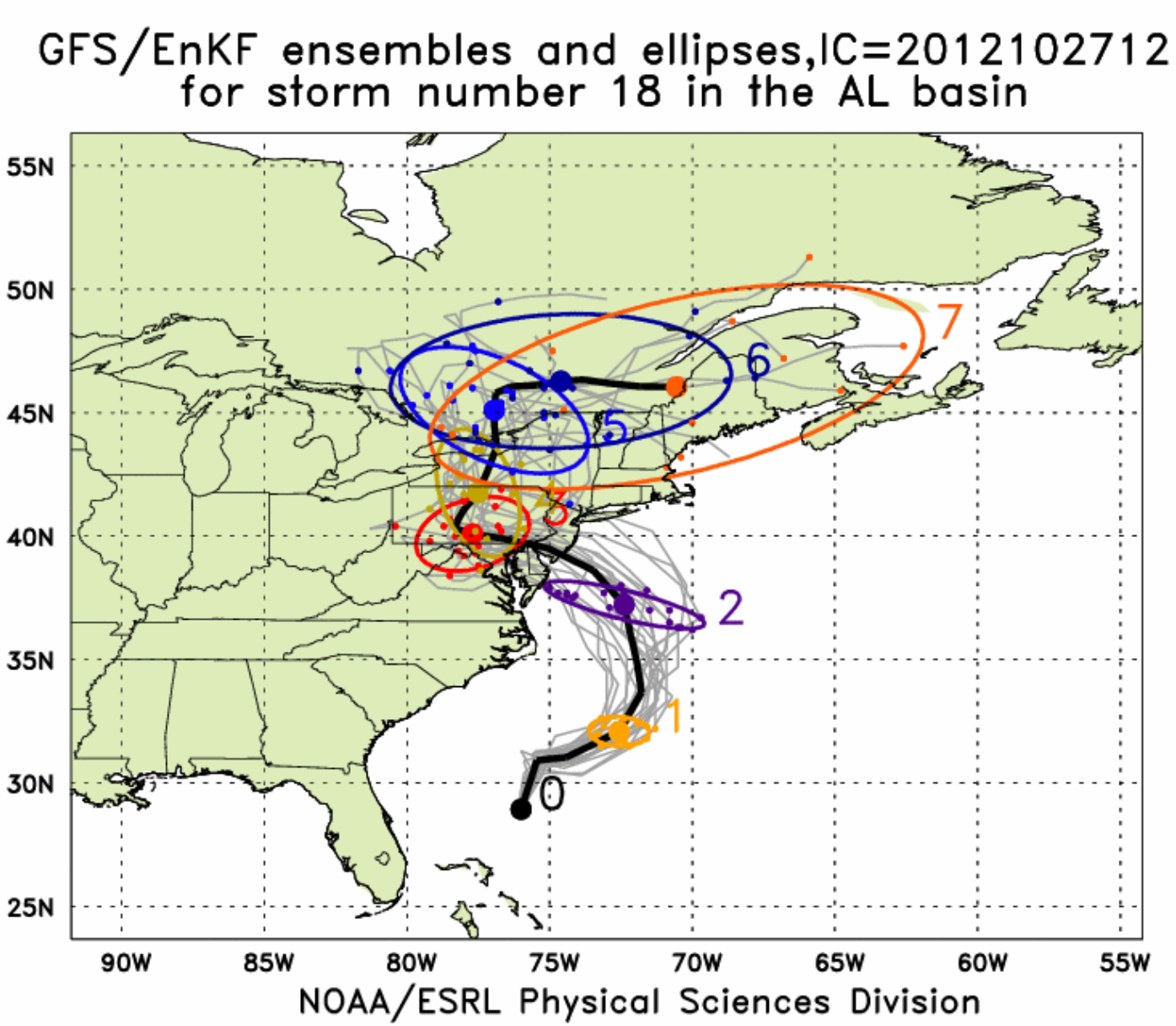
Hurricane Sandy



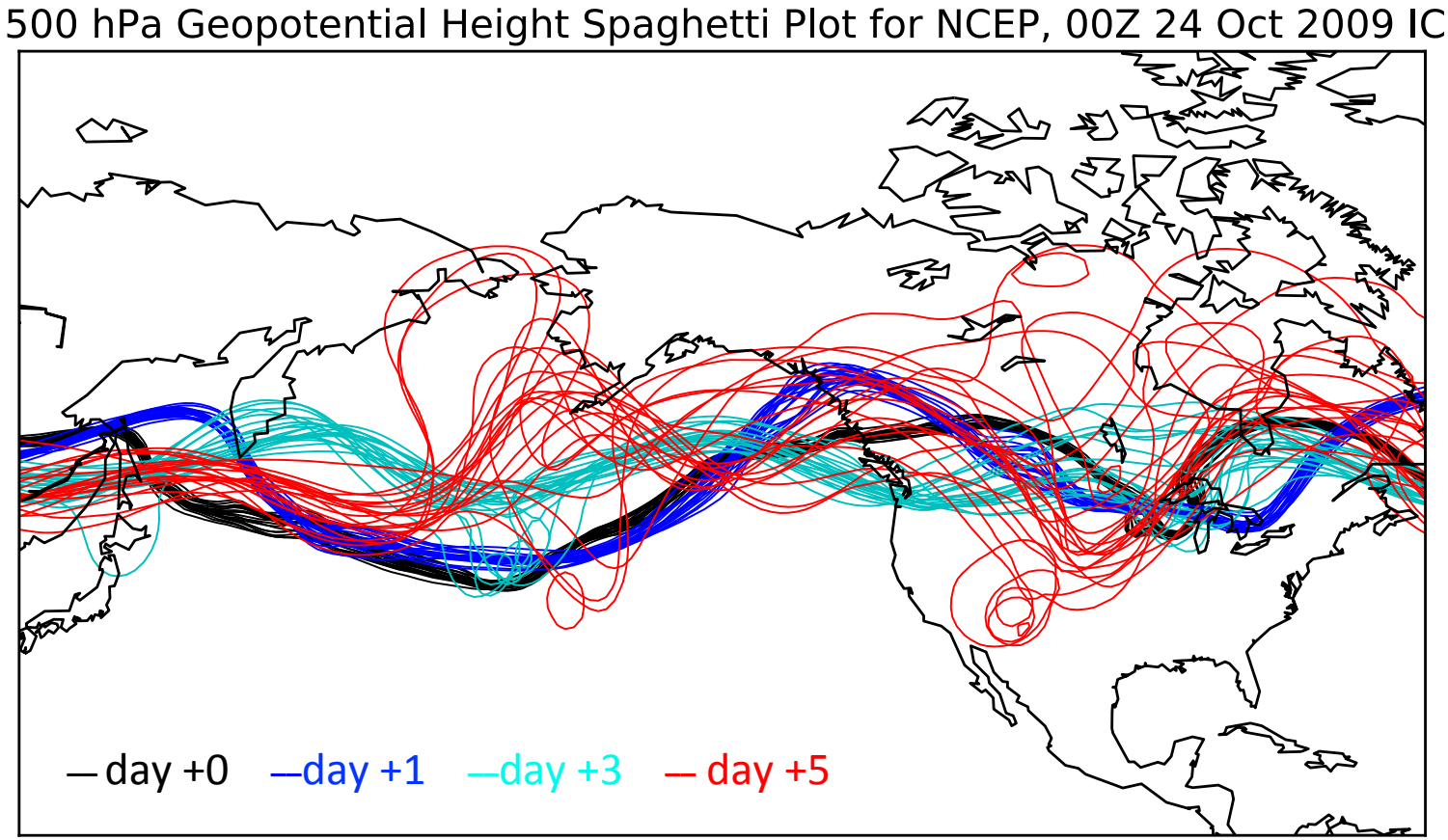
Hurricane Sandy



Hurricane Sandy

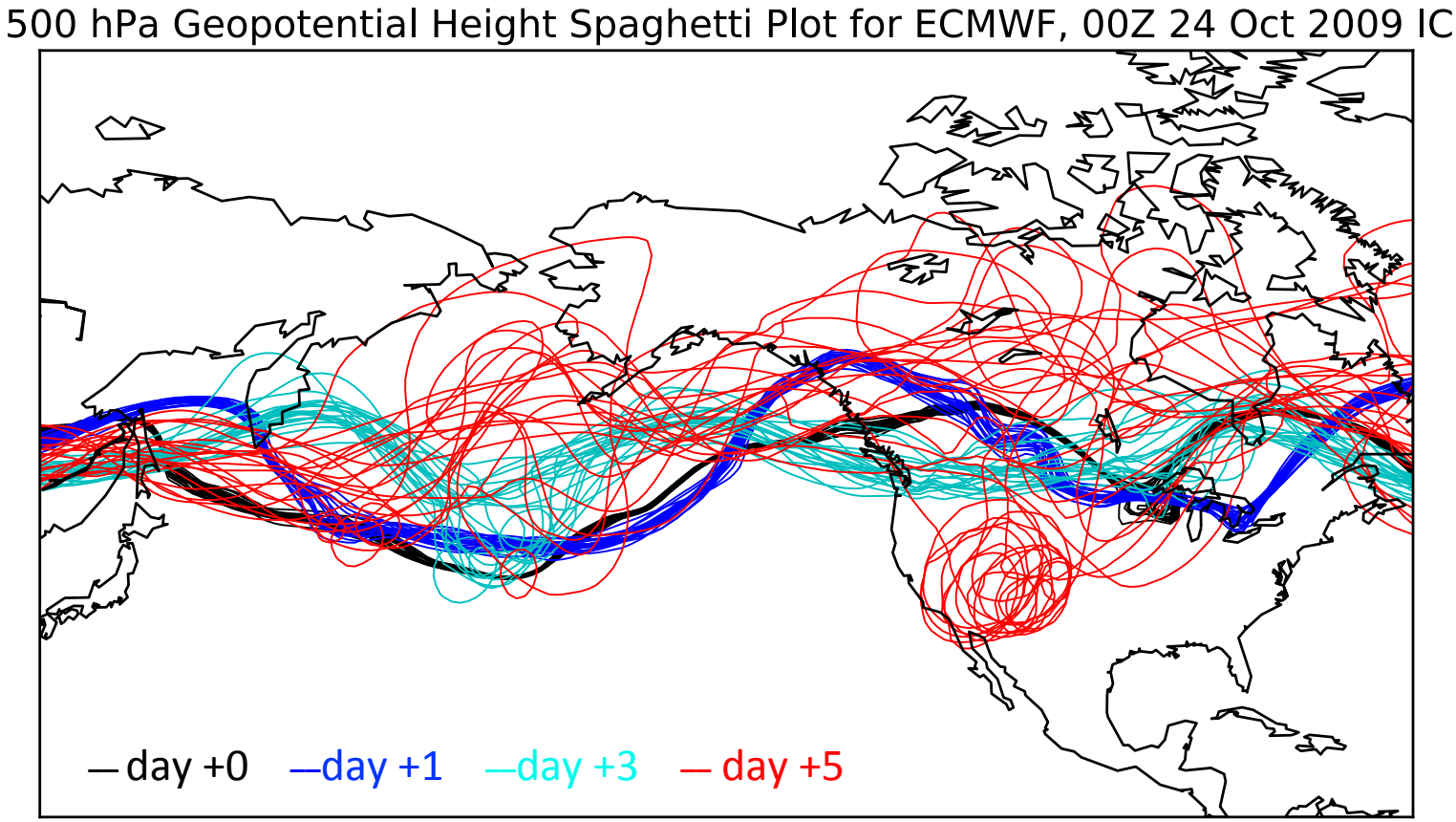


Previously: “Spaghetti plots”, NCEP ensemble
(546 dam contour, + 5 day forecast)



NCEP ensemble has only a hint in a few members of a major system affecting the southwest US.

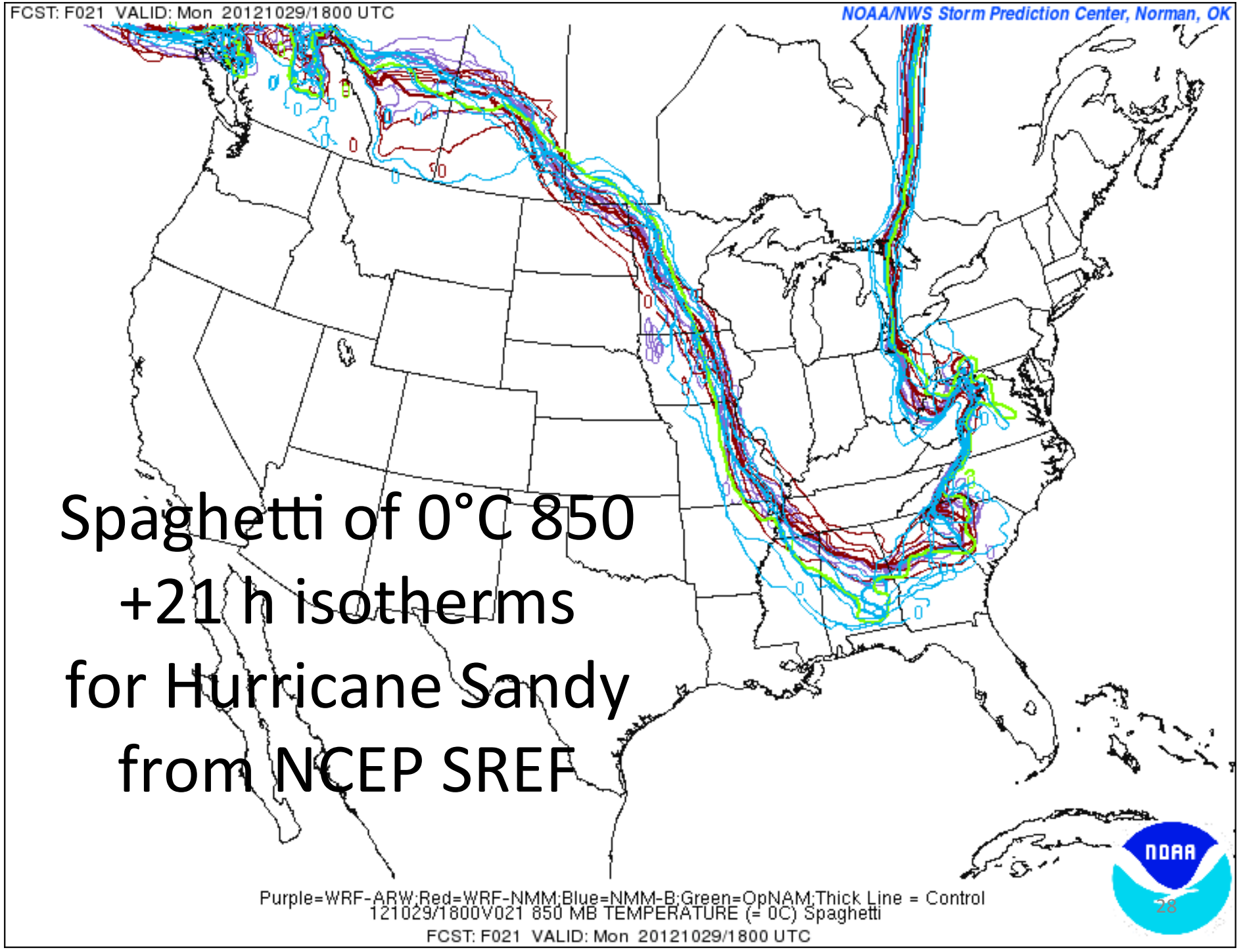
Previously: “Spaghetti plots”, ECMWF ensemble (546 dam contour + 5 day forecast)

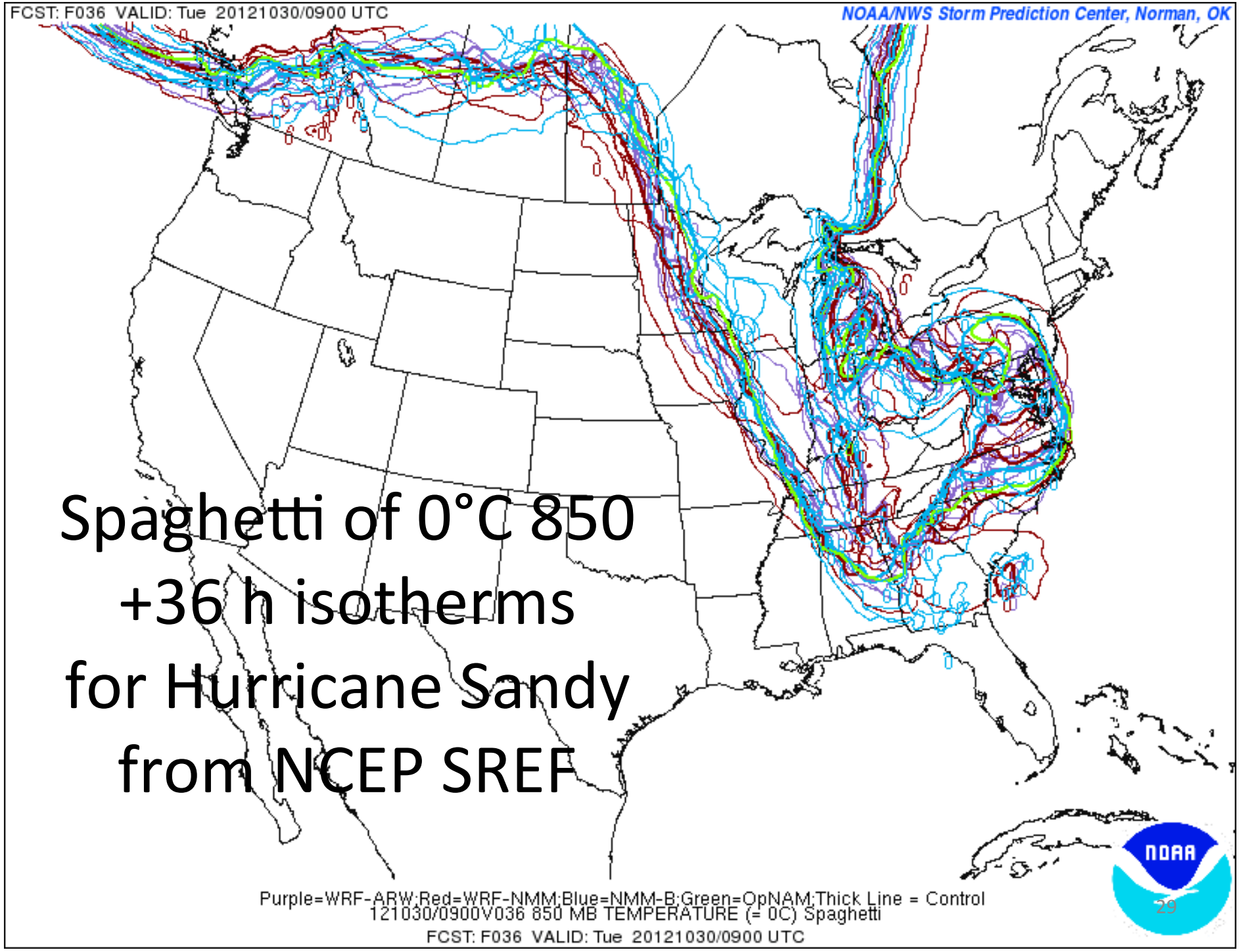


ECMWF system much better at predicting event in central Rockies. Lessons:

(1) Probabilistic, not deterministic forecasts, are definitely needed.

(2) A high-quality ensemble prediction system is a necessity for weather-climate prediction.


FCST: F021 VALID: Mon 20121029/1800 UTC
NOAA/NWS Storm Prediction Center, Norman, OK
Spaghetti of 0°C 850
+21 h isotherms
for Hurricane Sandy
from NCEP SREF
Purple=WRF-ARW;Red=WRF-NMM;Blue=NMM-B;Green=OpNAM;Thick Line = Control
121029/1800V021 850 MB TEMPERATURE (= 0C) Spaghetti
FCST: F021 VALID: Mon 20121029/1800 UTC
NOAA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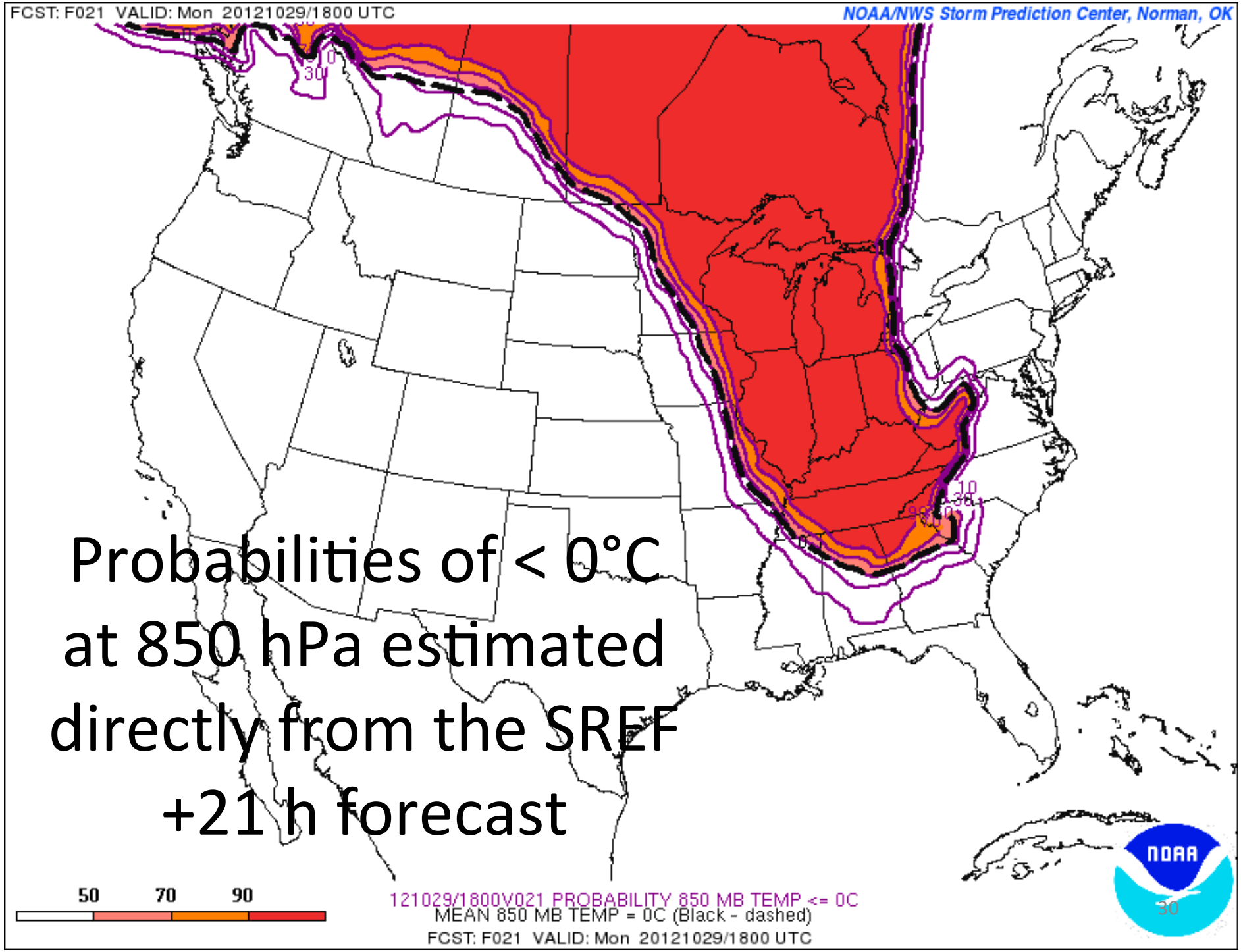
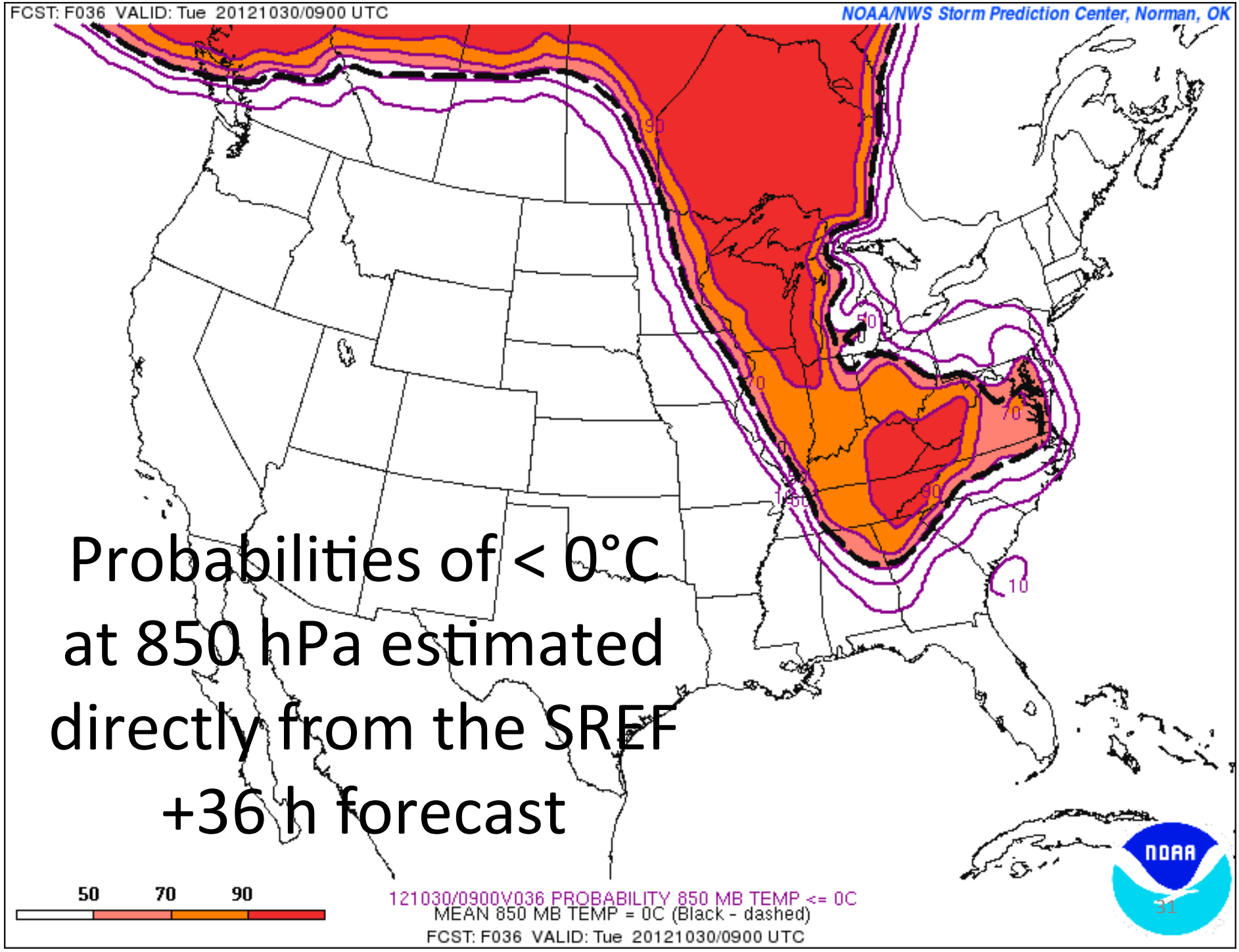
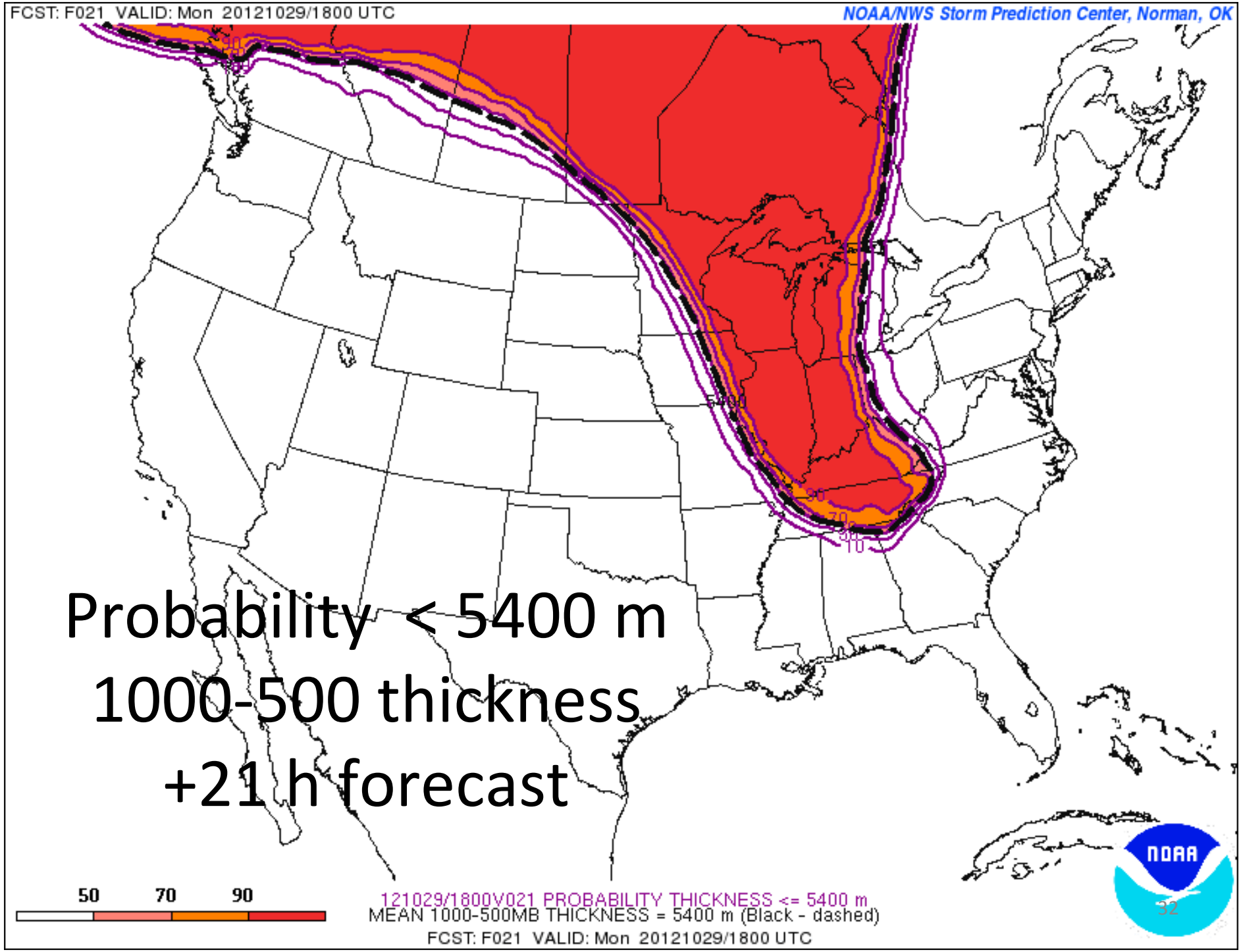
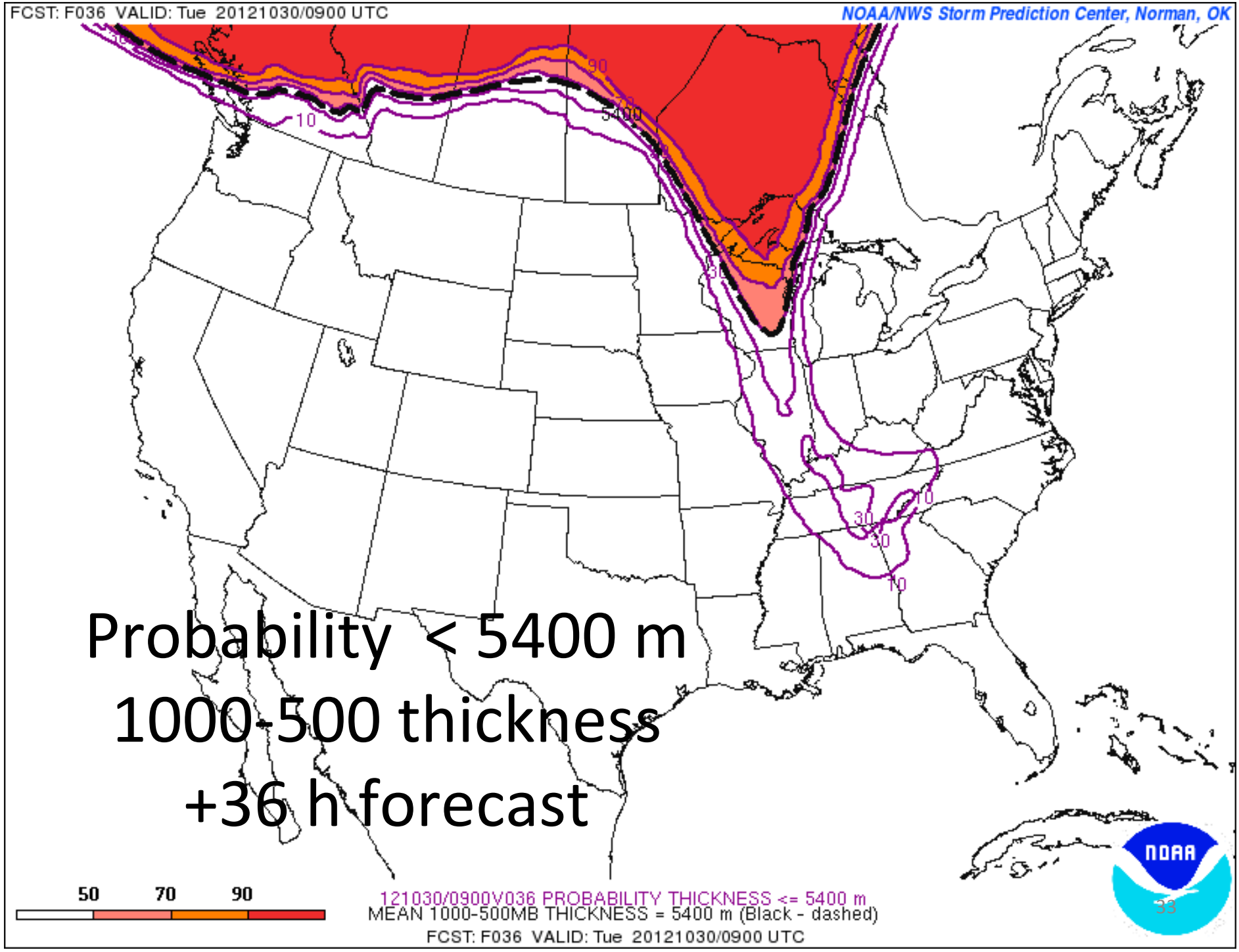
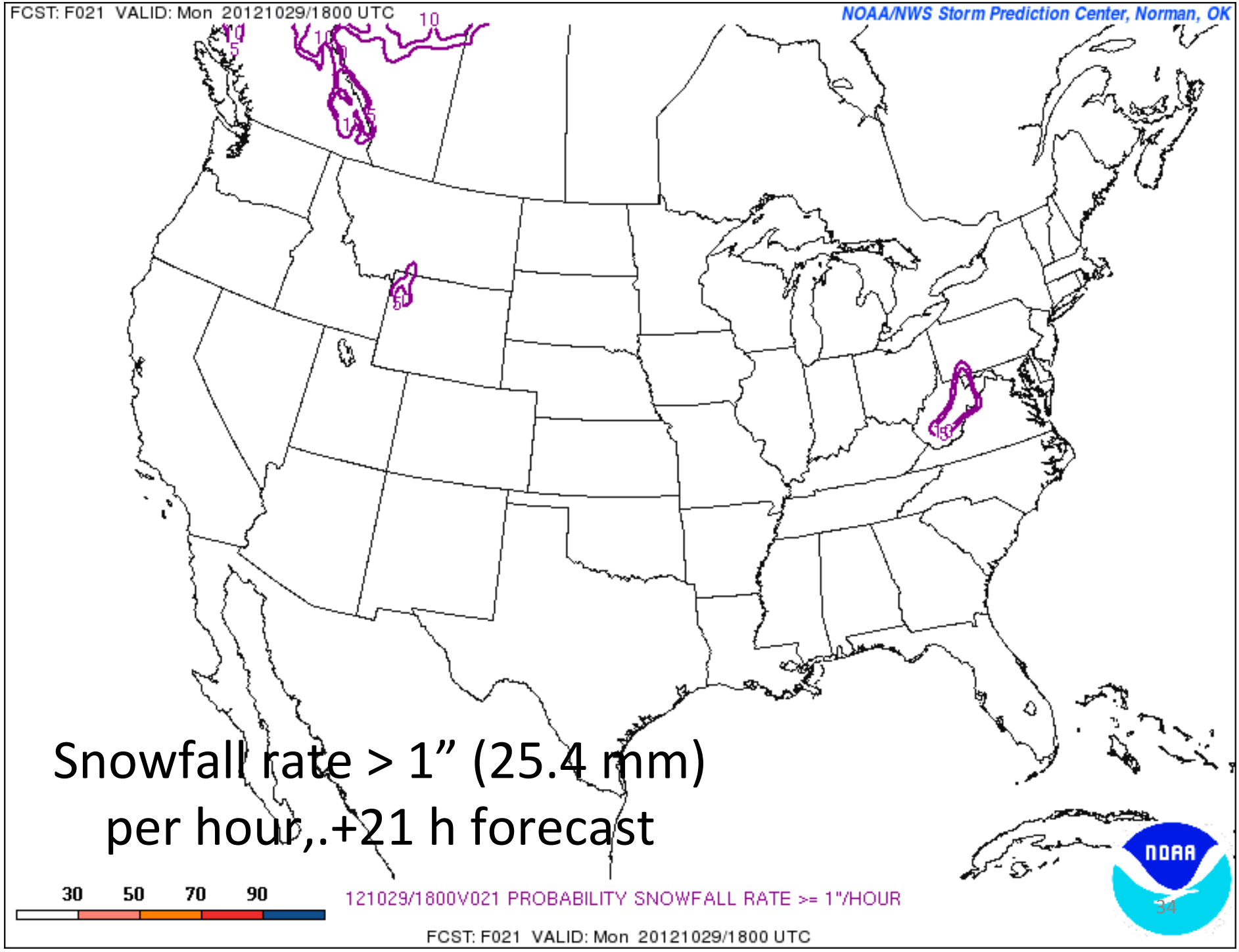
NOAA/NWS Storm Prediction Center, Norman, OK
Spaghetti of 0°C 850
+36 h isotherms
for Hurricane Sandy
from NCEP SREF
Purple=WRF-ARW;Red=WRF-NMM;Blue=NMM-B;Green=OpNAM;Thick Line = Control
121030/0900V036 850 MB TEMPERATURE (= 0C) Spaghetti
FCST: F036 VALID: Tue 20121030/0900 UTC
NOAA


FCST: F021 VALID: Mon 20121029/1800 UTC
NOAA/NWS Storm Prediction Center, Norman, OK
Probabilities of < 0°C
at 850 hPa estimated
directly from the SREF
+21 h forecast
50
70
90
121029/1800V021 PROBABILITY 850 MB TEMP <= 0C
MEAN 850 MB TEMP = 0C (Black - dashed)
FCST: F021 VALID: Mon 20121029/1800 UTC
NOAA
30

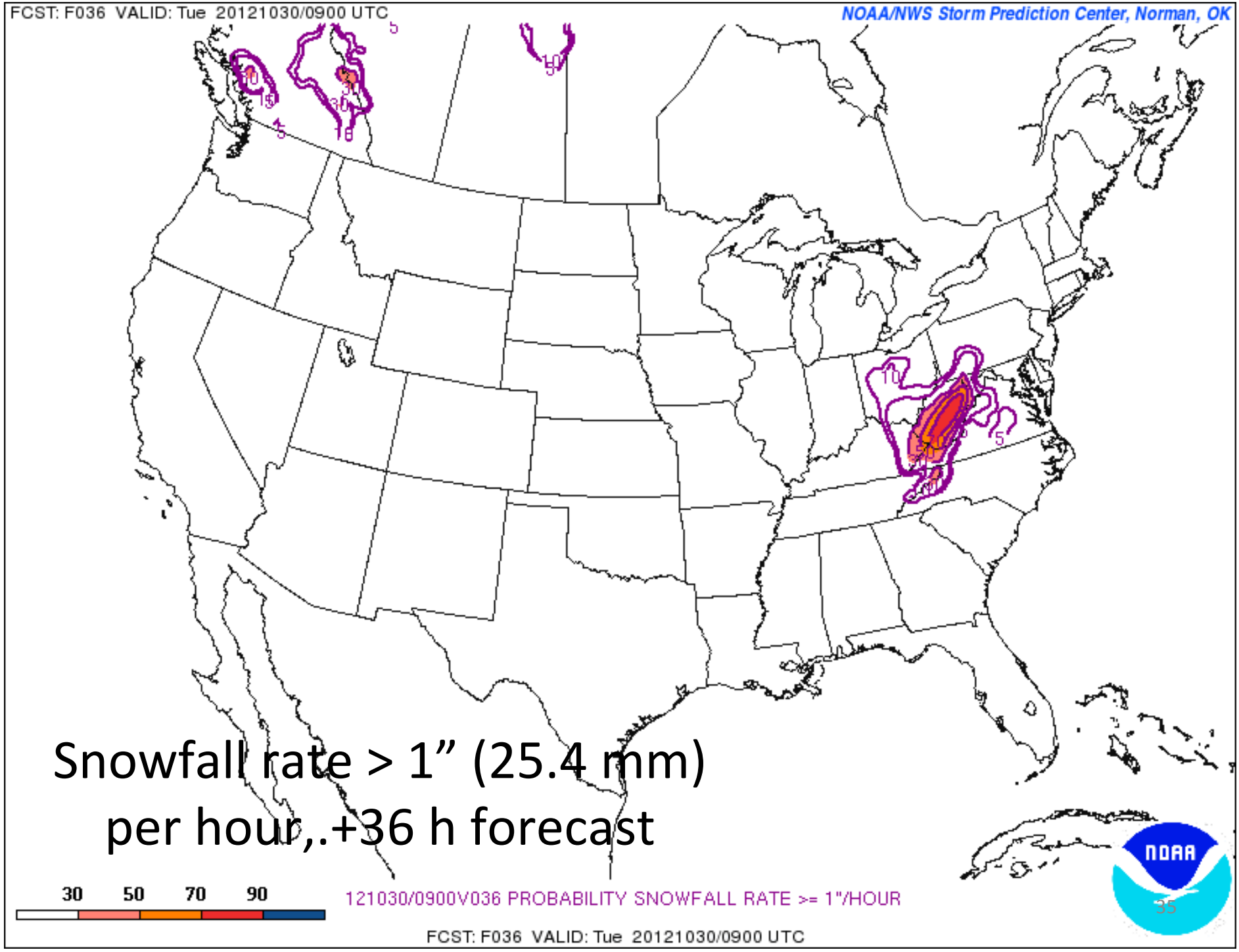

FCST: F036 VALID: Tue 20121030/0900 UTC
NOAA/NWS Storm Prediction Center, Norman, OK
Probabilities of < 0°C
at 850 hPa estimated
directly from the SREF
+36 h forecast
50
70
90
121030/0900V036 PROBABILITY 850 MB TEMP <= 0C
MEAN 850 MB TEMP = 0C (Black - dashed)
FCST: F036 VALID: Tue 20121030/0900 UTC
NOAA

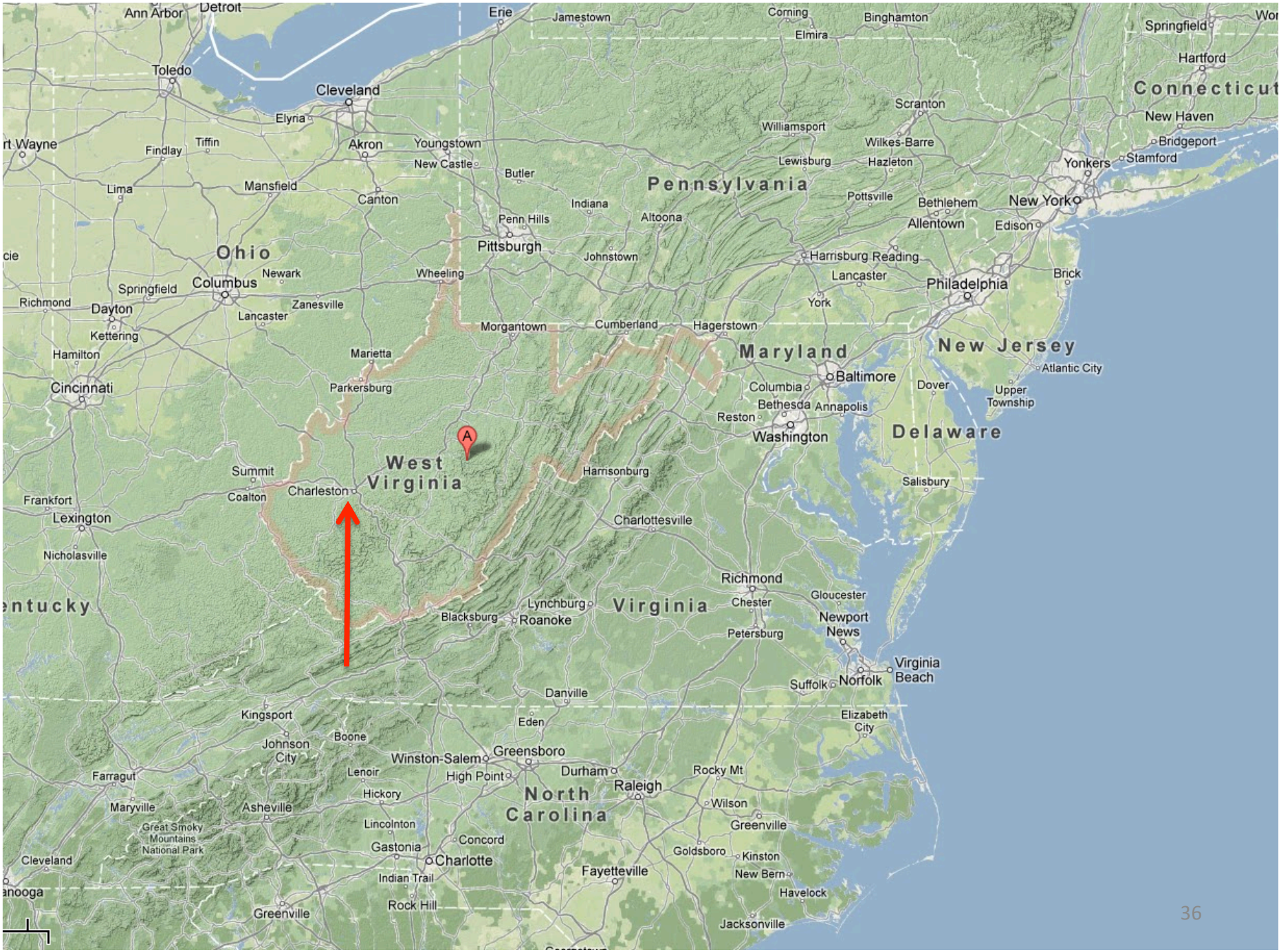

FCST: F021 VALID: Mon 20121029/1800 UTC
NOAA/NWS Storm Prediction Center, Norman, OK
Probability < 5400 m
1000-500 thickness
+21 h forecast
50
70
90
121029/1800V021 PROBABILITY THICKNESS <= 5400 m
MEAN 1000-500MB THICKNESS = 5400 m (Black - dashed)
FCST: F021 VALID: Mon 20121029/1800 UTC
NOAA


FCST: F036 VALID: Tue 20121030/0900 UTC
NOAA/NWS Storm Prediction Center, Norman, OK
Probability < 5400 m
1000-500 thickness
+36 h forecast
50
70
90
121030/0900V036 PROBABILITY THICKNESS <= 5400 m
MEAN 1000-500MB THICKNESS = 5400 m (Black - dashed)
FCST: F036 VALID: Tue 20121030/0900 UTC
NOAA



Snowfall rate > 1” (25.4 mm) per hour,.+21 h forecast


FCST: F036 VALID: Tue 20121030/0900 UTC
NOAA/NWS Storm Prediction Center, Norman, OK
Snowfall rate > 1” (25.4 mm) per hour,.+36 h forecast
30 50 70 90
121030/0900V036 PROBABILITY SNOWFALL RATE >= 1"/HOUR
FCST: F036 VALID: Tue 20121030/0900 UTC
NOAA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Ann Arbor
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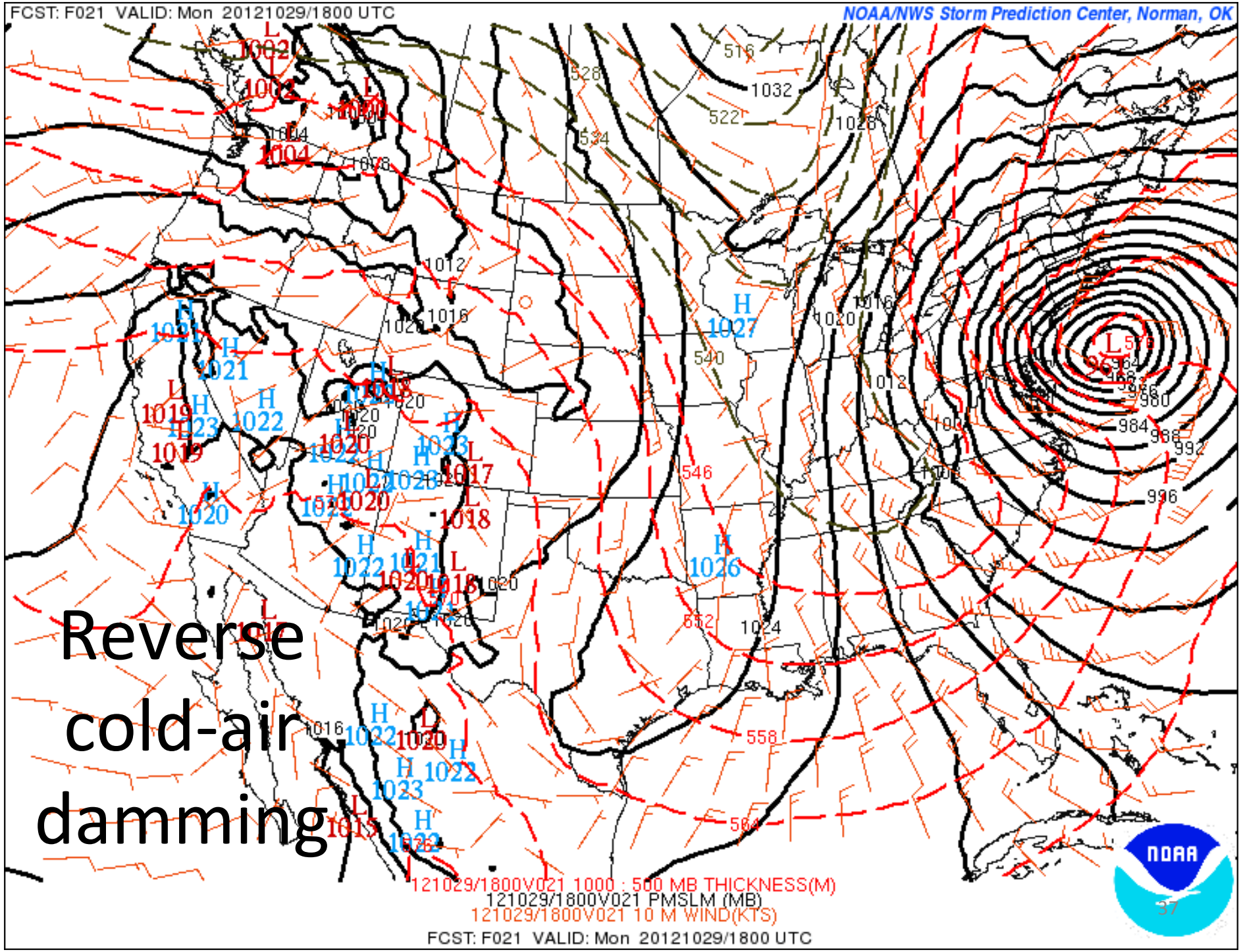
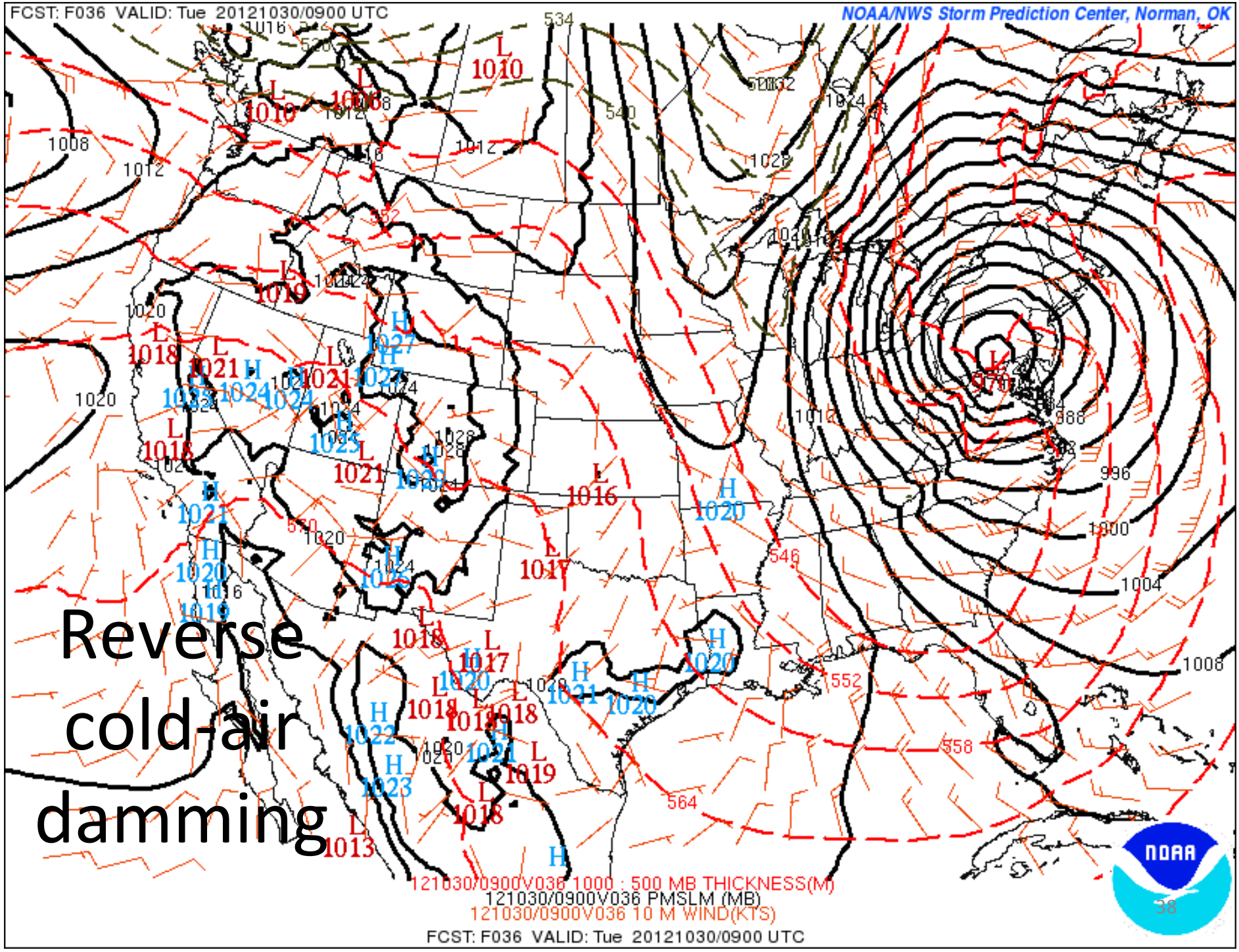
Williamsport
Wilkes-Barre
Bridgeport
Findlay
Tiffin
Akron
Youngstown
Lewisburg
Hazleton
Yonkers
Stamford
New Castle
Butler
Lima
Mansfield
Canton
Pennsylvania
Pottsville
Bethlehem
New York
Indiana
Penn Hills
Altoona
Allentown
Edison
Pittsburgh
Ohio
Johnstown
Harrisburg
Reading
Newark
Wheeling
Lancaster
Brick
Springfield
Columbus
Philadelphia
Richmond
Dayton
Zanesville
York
Lancaster
Morgantown
Cumberland
Hagerstown
Kettering
Maryland
New Jersey
Hamilton
Marietta
Atlantic City
Baltimore
Cincinnati
Parkersburg
Columbia
Dover
Upper Township
Bethesda
Annapolis
Reston
Washington
Delaware
Summit
West Virginia
Harrisonburg
Charleston
Salisbury
Coalton
Frankfort
Lexington
Charlottesville
Nicholasville
Richmond
Lynchburg
Virginia
Chester
Gloucester
Blacksburg
Roanoke
Newport News
Petersburg
Virginia Beach
Suffolk
Norfolk
Danville
Kingsport
Eden
Elizabeth City
Johnson City
Boone
Winston-Salem
Greensboro
Durham
Rocky Mt
Farragut
Lenoir
High Point
Raleigh
Hickory
North Carolina
Wilson
Maryville
Asheville
Greenville
Great Smoky Mountains National Park
Lincolnton
Concord
Gastonia
Goldsboro
Kinston
Cleveland
Charlotte
Fayetteville
New Bern
Indian Trail
Havelock
Rock Hill
Greenville
Jacksonville


FCST: F021 VALID: Mon 20121029/1800 UTC
NOAA/NWS Storm Prediction Center, Norman, OK
Reverse cold-air damming
121029/1800V021 1000 : 500 MB THICKNESS(M)
121029/1800V021 PMSLM (MB)
121029/1800V021 10 M WIND(KTS)
FCST: F021 VALID: Mon 20121029/1800 UTC
NOAA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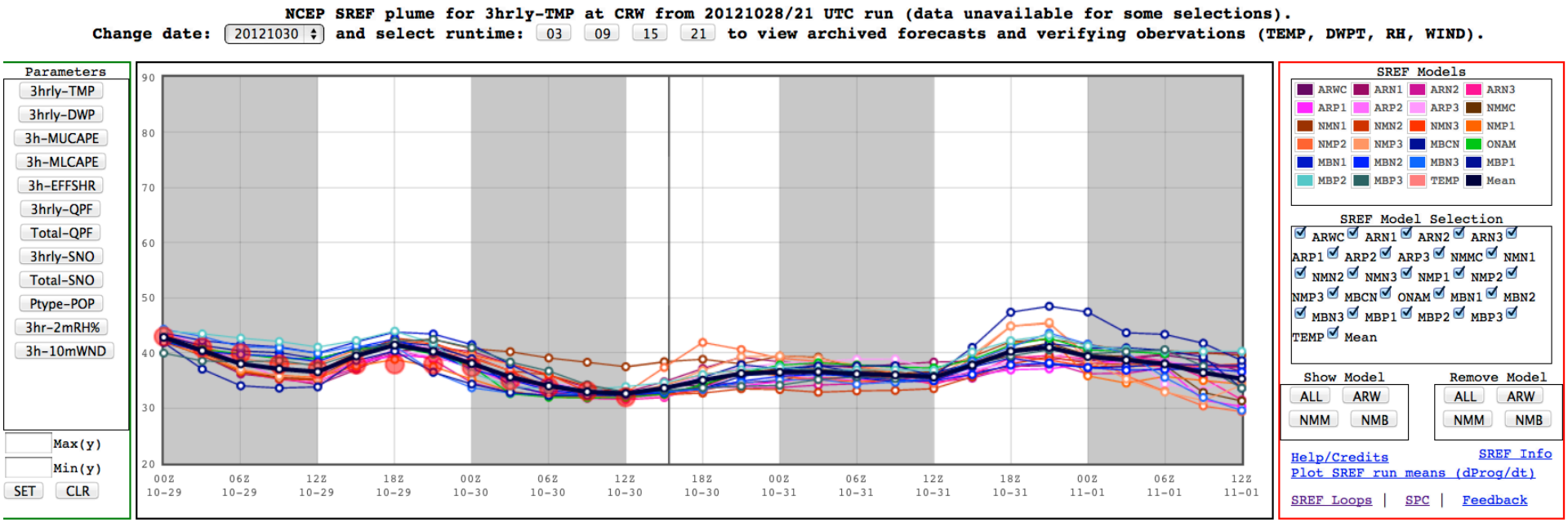
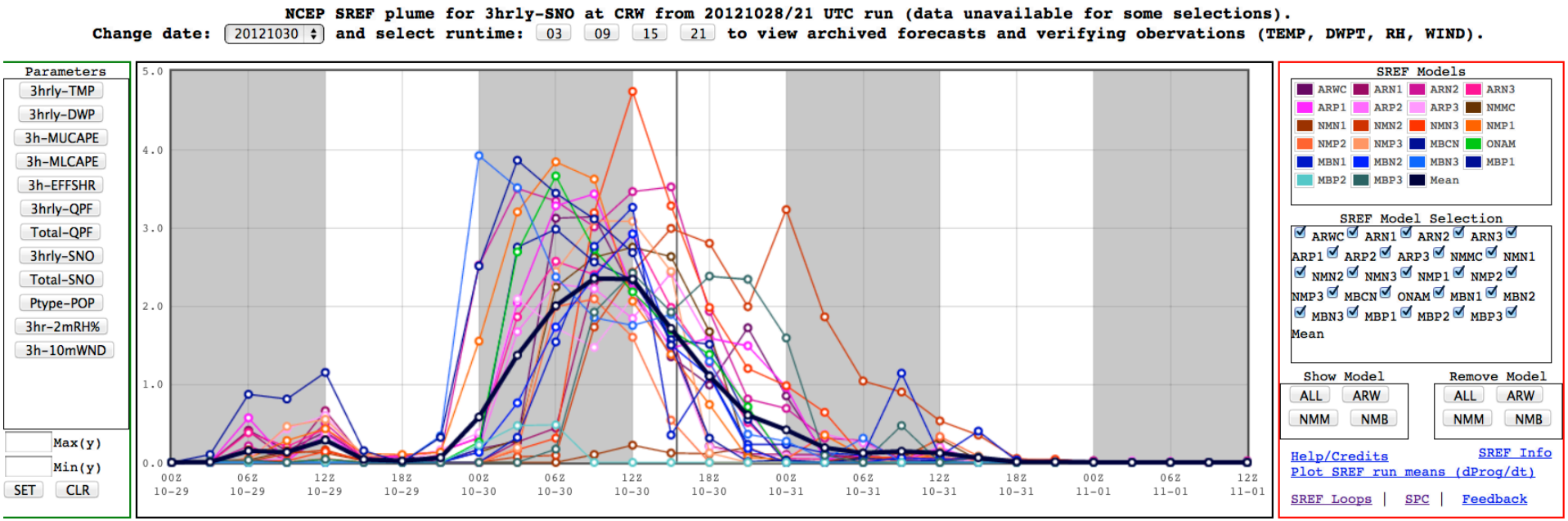
NOAA/NWS Storm Prediction Center, Norman, OK
Reverse cold-air damming
121030/0900V036 1000 : 500 MB THICKNESS(M)
121030/0900V036 PMSLM (MB)
121030/0900V036 10 M WIND(KTS)
FCST: F036 VALID: Tue 20121030/0900 UTC
NOAA

2-m temperature “plume diagrams” for CRW (Charleston) West Virginia

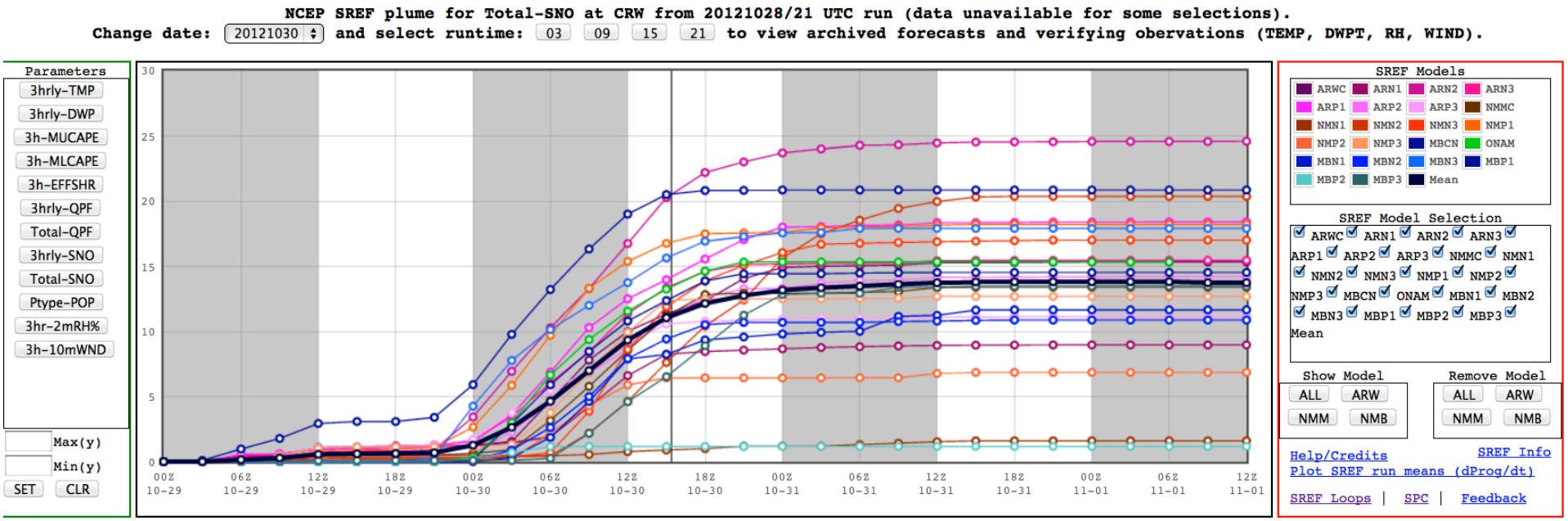


3-hourly snowfall accumulation for CRW (Charleston) West Virginia



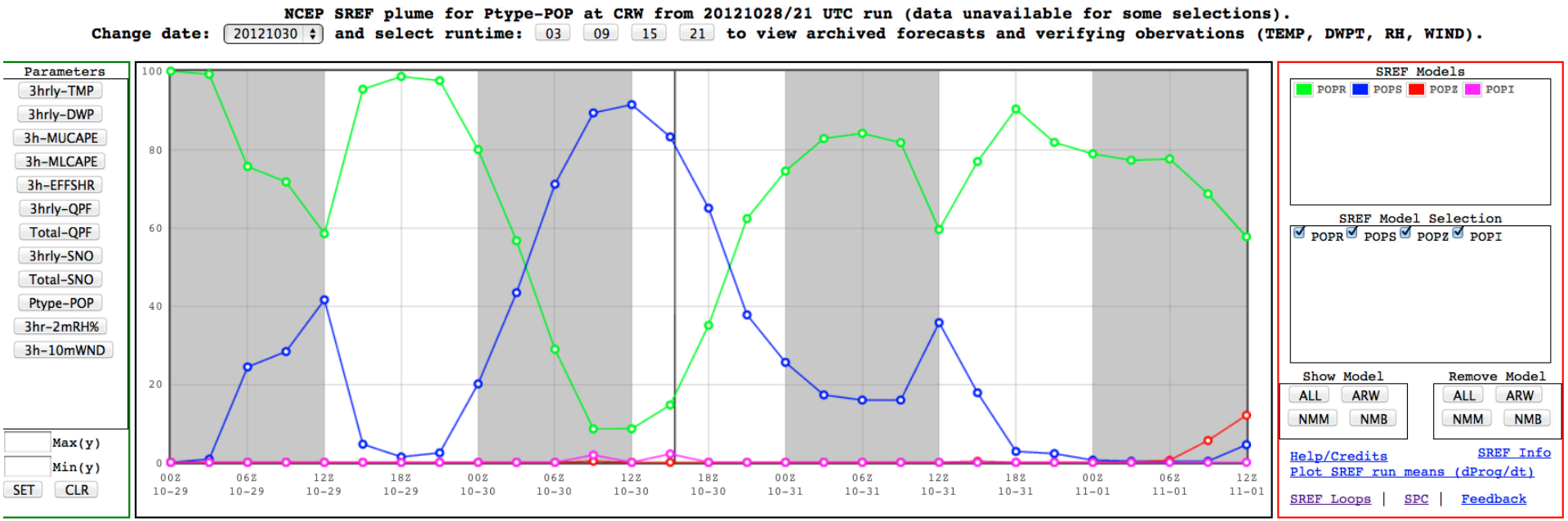
Provides you with information on the range of possible starting and ending times, peak snowfall rates.

Accumulated snowfall “plume diagrams” for CRW (Charleston) West Virginia

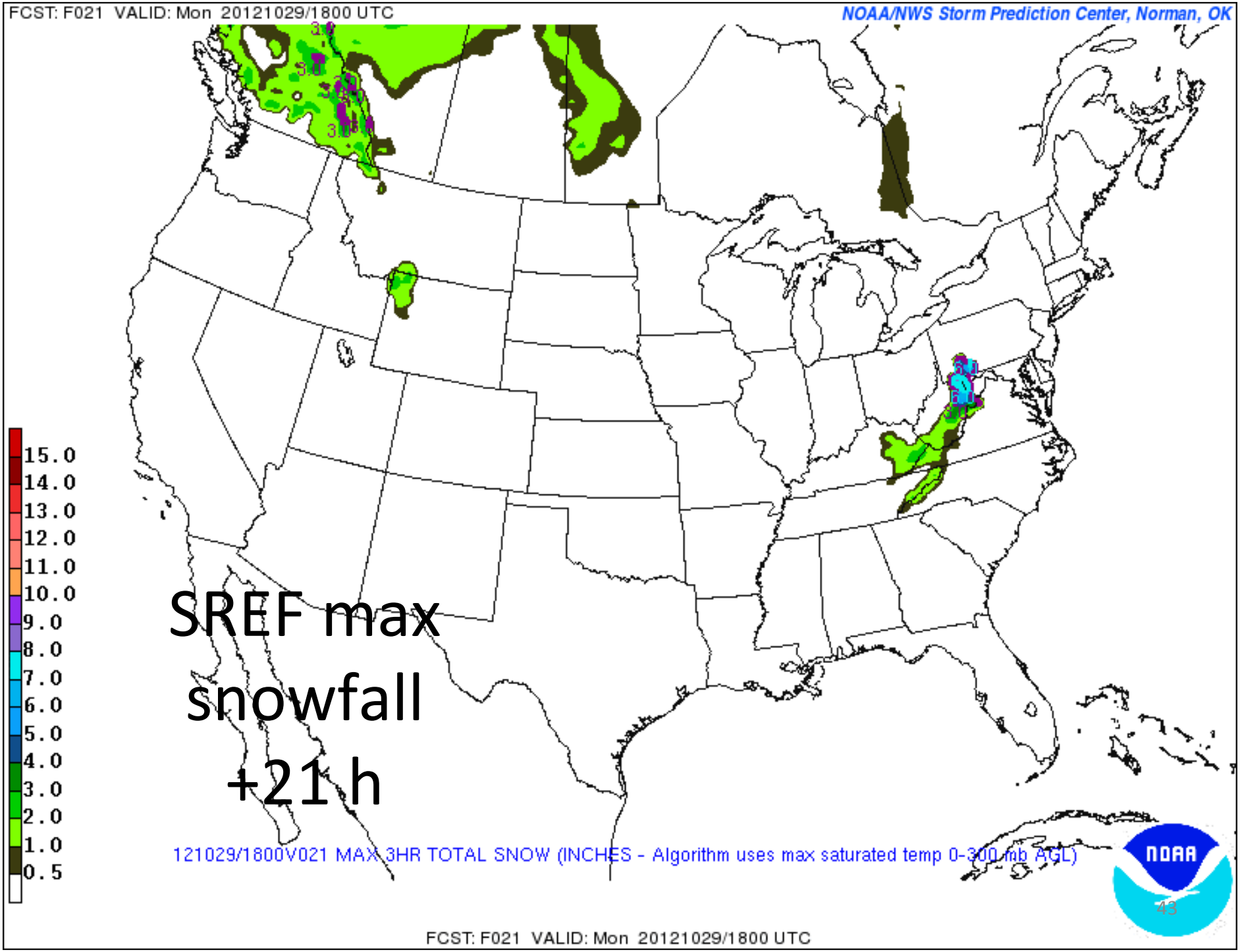


Provides you with help in estimating the range of total snowfall

Probability of precipitation type for CRW (Charleston) West Virginia



Helpful in estimating probability of precipitation type.


FCST: F021 VALID: Mon 20121029/1800 UTC
NOAA/NWS Storm Prediction Center, Norman, OK
15.0
14.0
13.0
12.0
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9.0
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4.0
3.0
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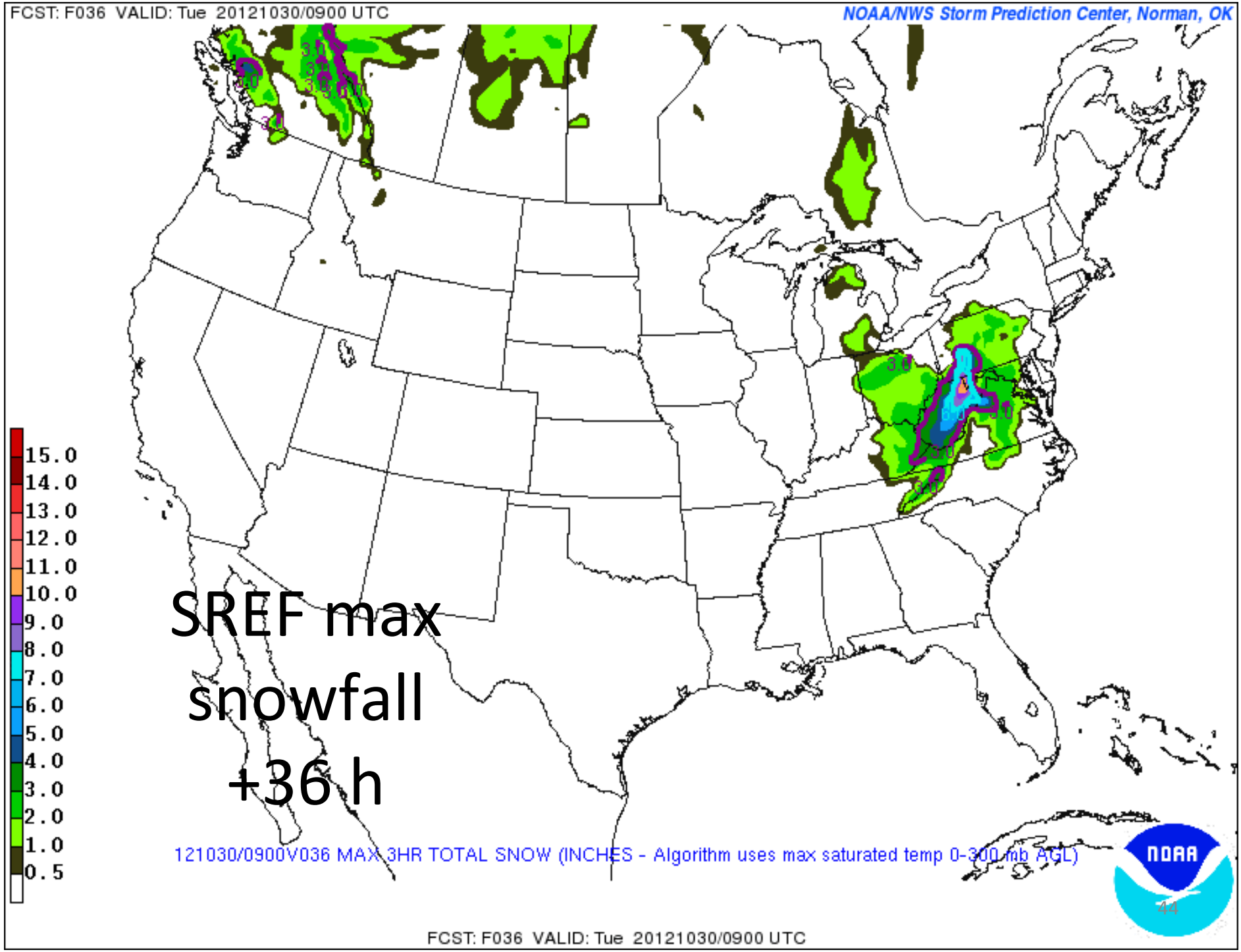
1.0
0.5
SREF max
snowfall
+21 h
121029/1800V021 MAX 3HR TOTAL SNOW (INCHES - Algorithm uses max saturated temp 0-300 mb AGL)
NOAA
43
FCST: F021 VALID: Mon 20121029/1800 UTC


FCST: F036 VALID: Tue 20121030/0900 UTC
NOAA/NWS Storm Prediction Center, Norman, OK
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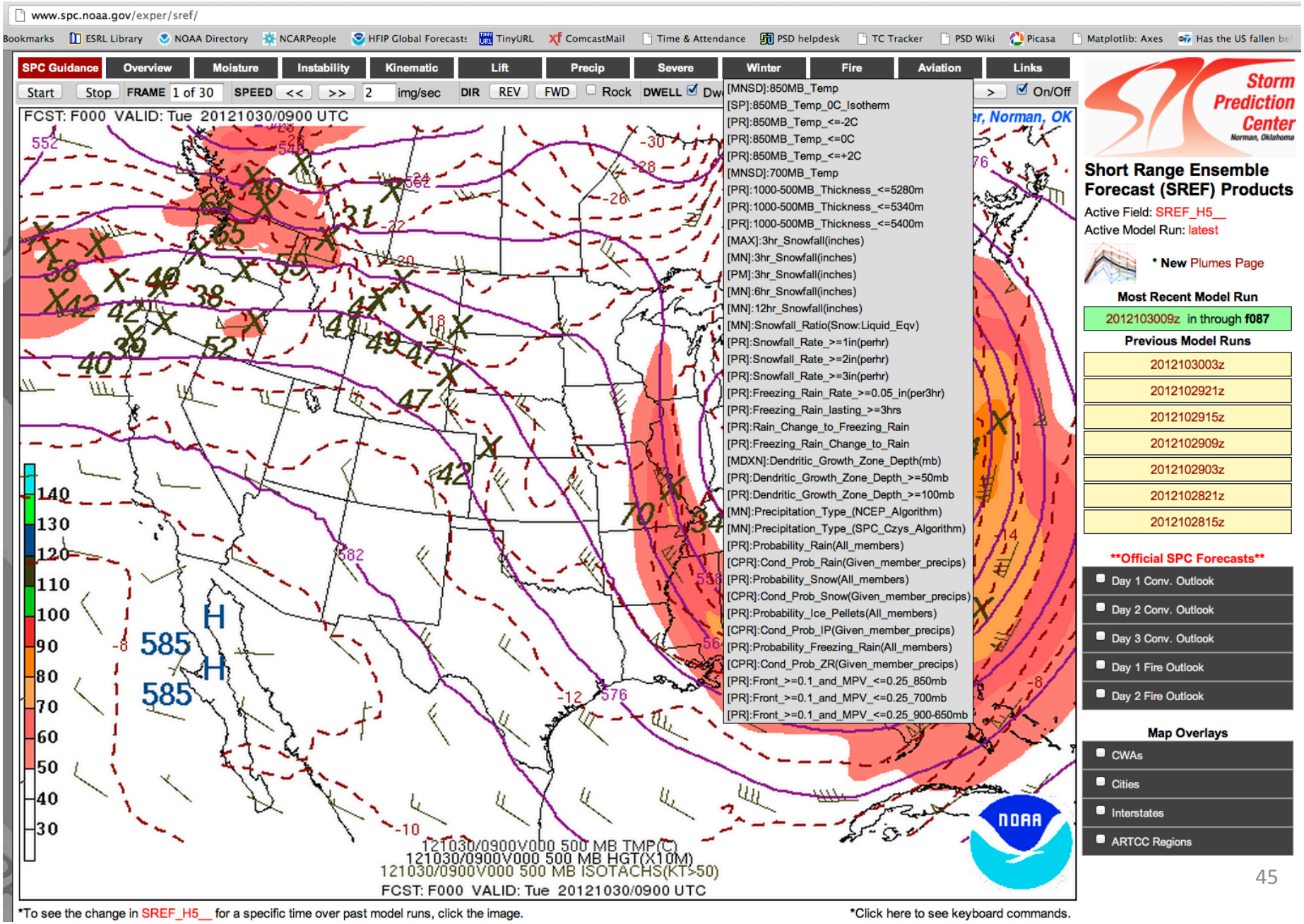
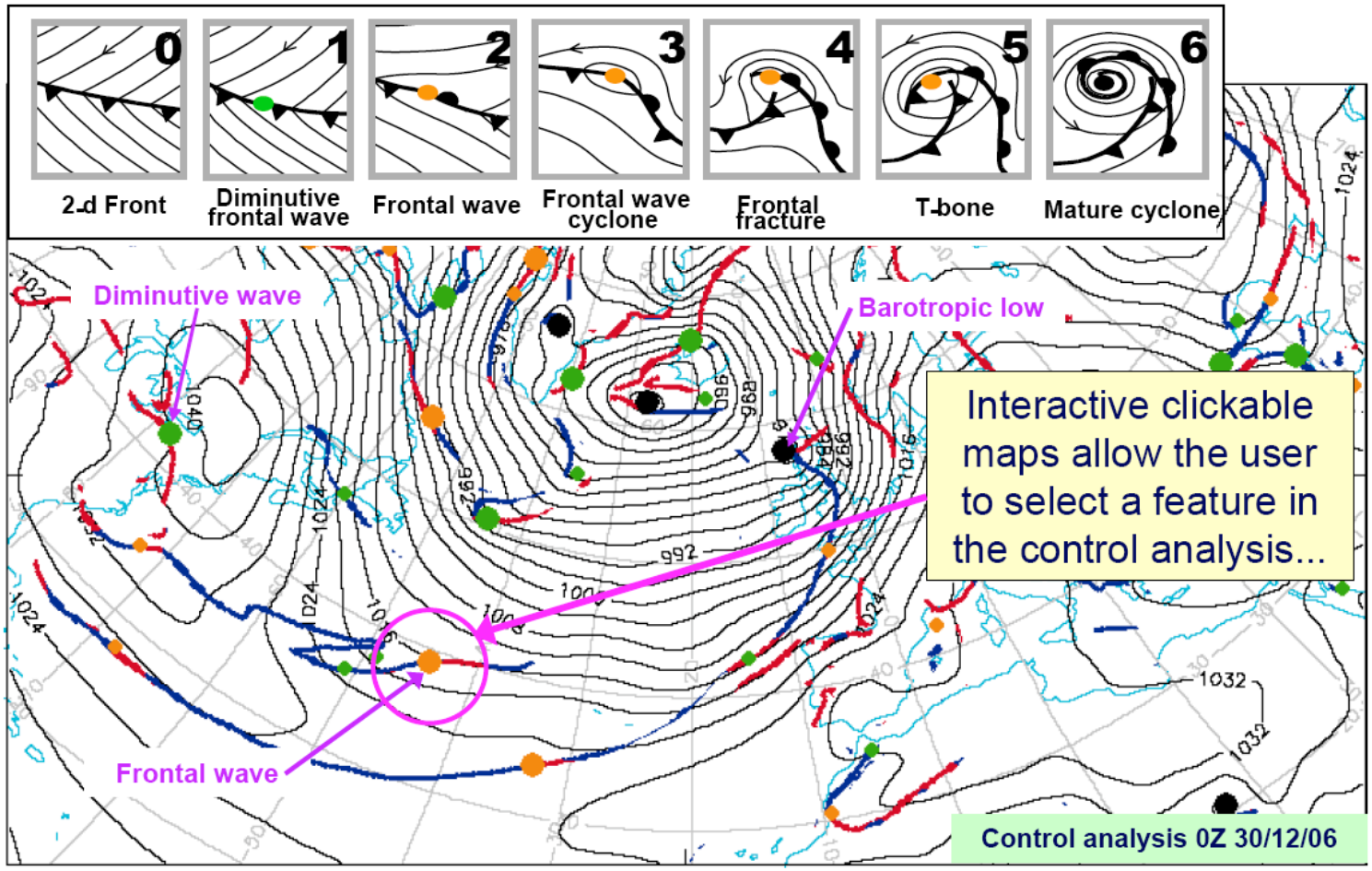
2.0
1.0
0.5
SREF max
snowfall
+36 h
121030/0900V036 MAX 3HR TOTAL SNOW (INCHES - Algorithm uses max saturated temp 0-300 mb AGL)
NOAA
FCST: F036 VALID: Tue 20121030/0900 UTC

Many other products at http://www.spc.noaa.gov/exper/sref/



Some other ideas for creatively displaying and using ensemble data

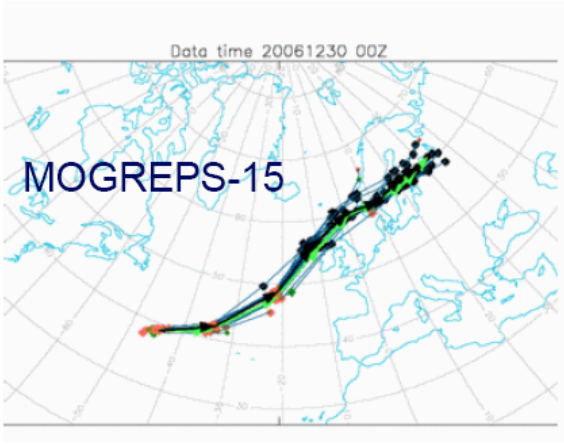
Cyclone database & New Year's Eve storm

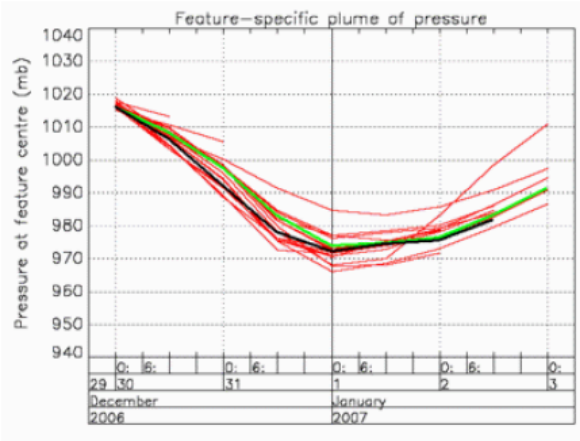


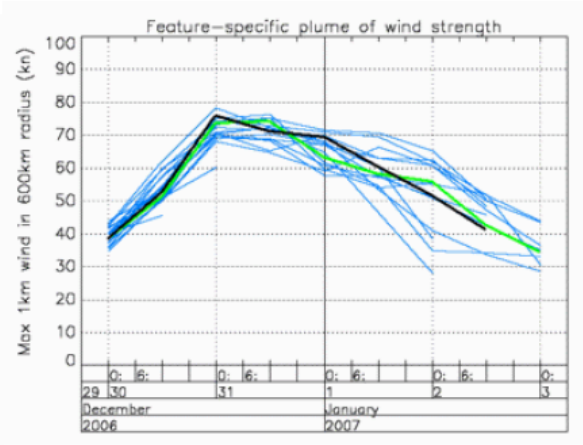
- Tracking scheme uses a combination of forward and backward tracking. It uses extrapolation and 500hPa steering wind to estimate positions, and matches features based on separation distance, type and thickness

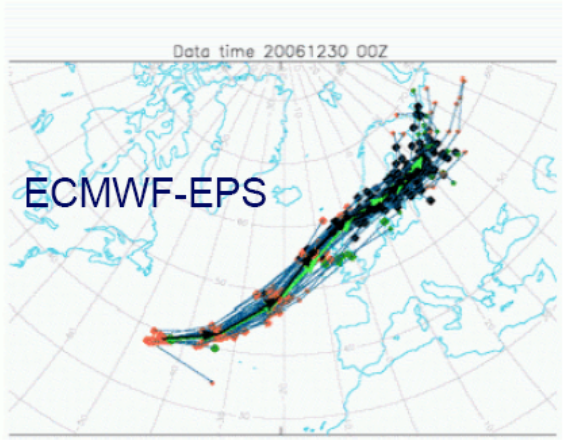
Cyclone database: 31/12/2006 example

- Clicking on a feature brings up feature-specific tracks from each ensemble member and matching plumes of intensity measures to identify the potential for high-impact weather

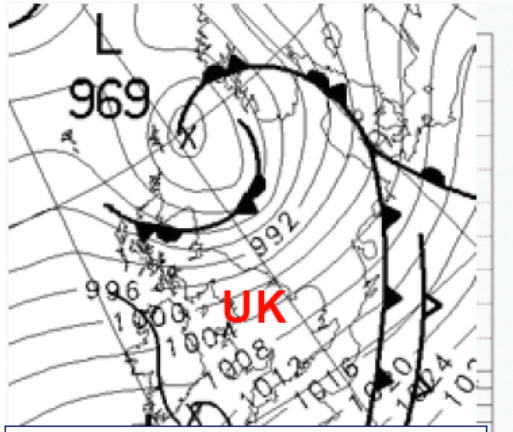








This storm tracked across Scotland, with gusts up to 100mph, leading to the high-profile cancellation of New Year's Eve celebrations and loss of power to 1000s of homes



Analysis 00Z 01/01/2007

Mean and (normalized) standard deviation

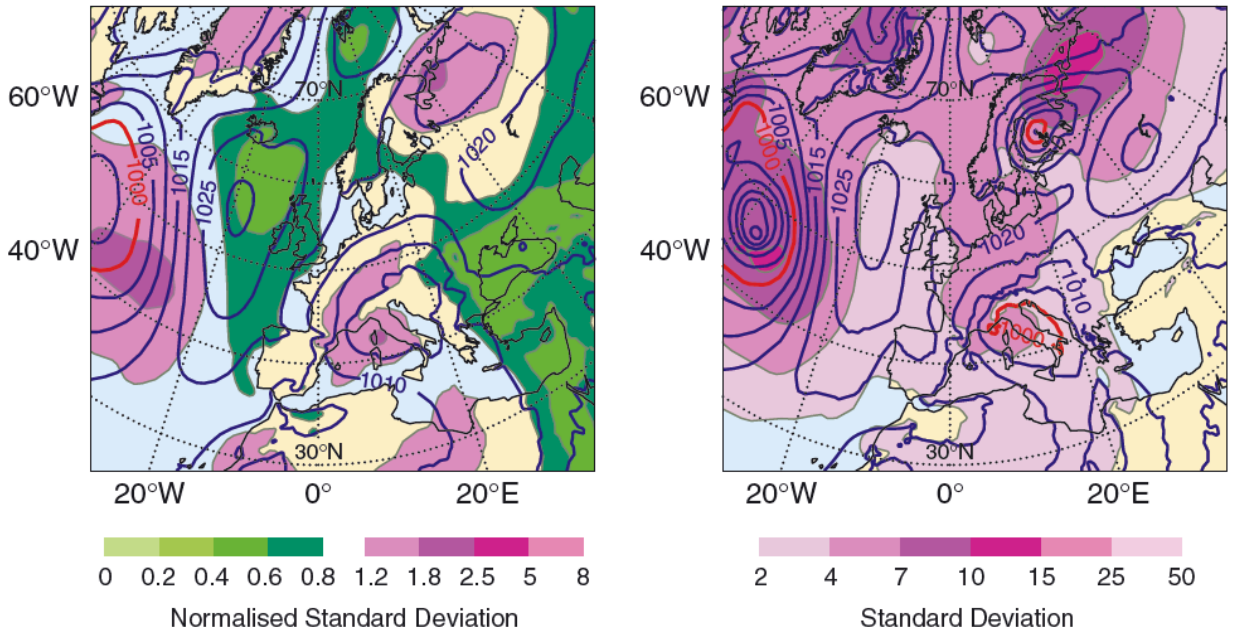
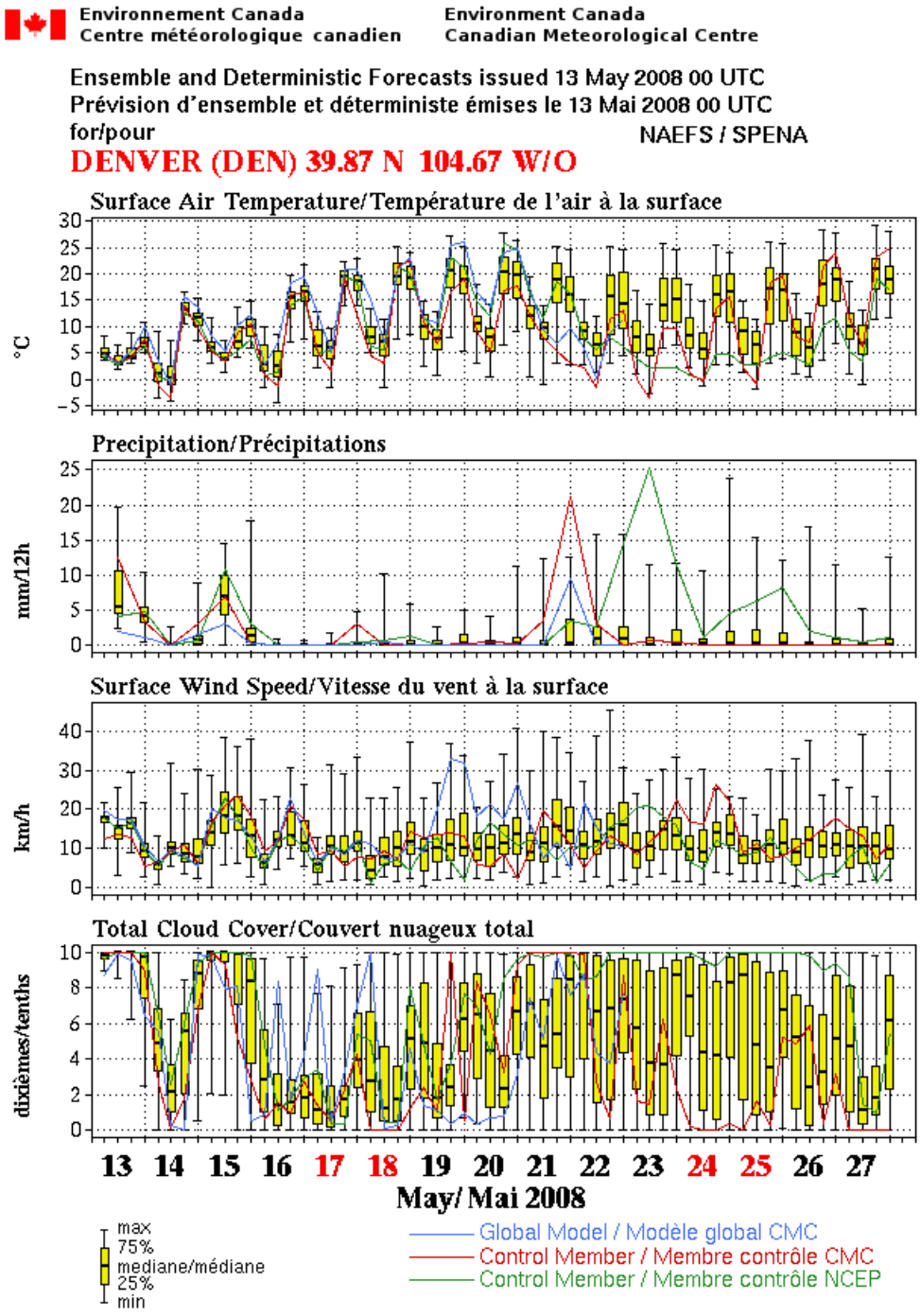


Figure 3. Ensemble mean and spread. The contours show the forecast mean sea-level pressure (MSLP) field for six days ahead from the ensemble-mean (left panel) and the single higher resolution 'deterministic' forecast (right panel). The spread within the ensemble is also represented on each panel, using coloured shading. On the right panel, spread is simply represented as the standard deviation. Small values (light shading) indicate small spread differences between the ensemble members and hence high confidence, while large values indicate large differences and therefore low confidence. The shading on the left panel shows a normalised standard deviation, putting the spread into the context of the general ensemble behaviour, in that area, over the last 30 days. In this example the spread indicates relatively high confidence (green) in the high pressure area over the UK, but more uncertainty (purple) in the low pressure areas in the Mediterranean and Atlantic. These charts are updated daily at http://www.ecmwf.int/products/forecasts/d/charts/medium/eps/

Ensemble products for weather forecasters
Weather – September 2011, Vol. 66, No. 9

c/o D. Richardson & ECMWF Newsletter

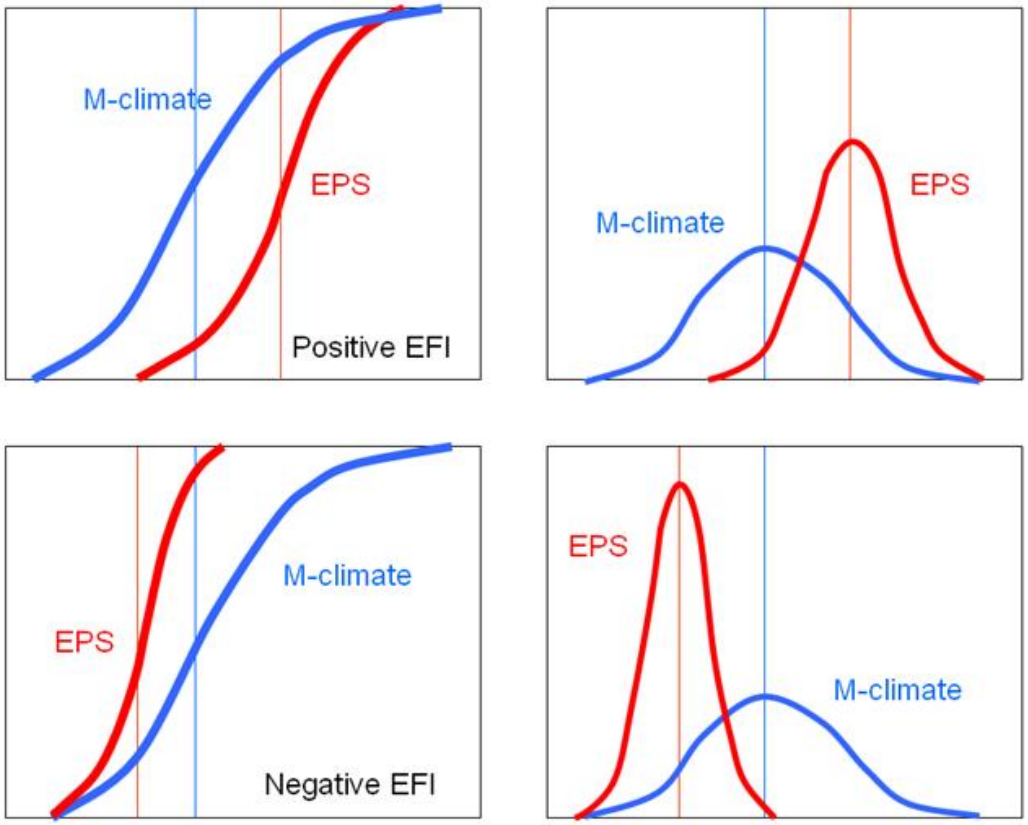


EPSgrams from RPN Canada

Using reforecasts in the absence of observations: the "Extreme Forecast Index"

http://www.ecmwf.int/products/forecasts/guide/Calculating_the_EFI.html

$$EFI = \frac{2}{\pi}\int_0^1 \frac{p - F_f(p)}{\sqrt{p(1-p)}}\mathrm{dp}$$



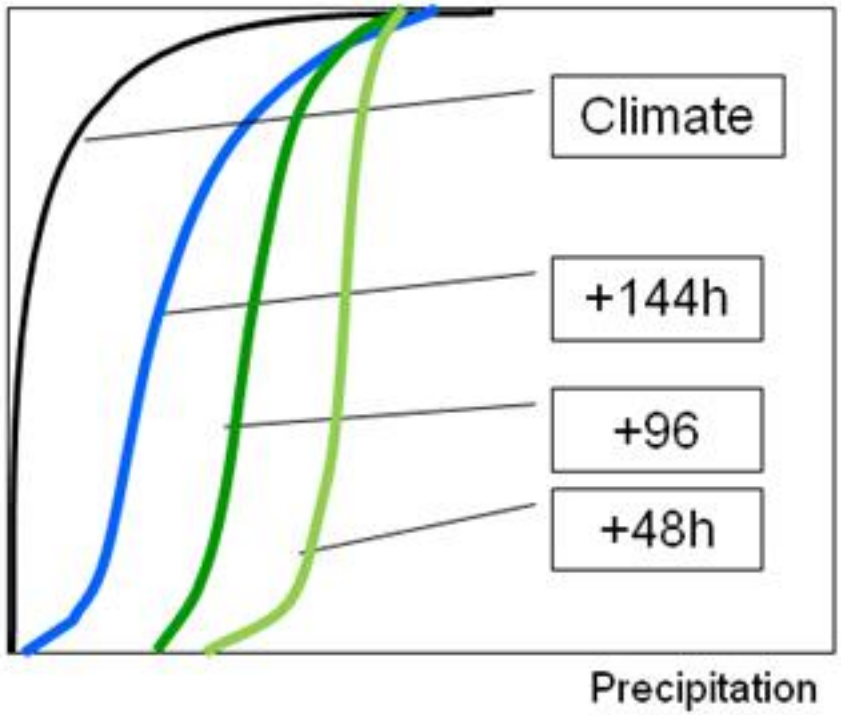
We previously talked about statistical post-processing as a way of dealing with model bias.

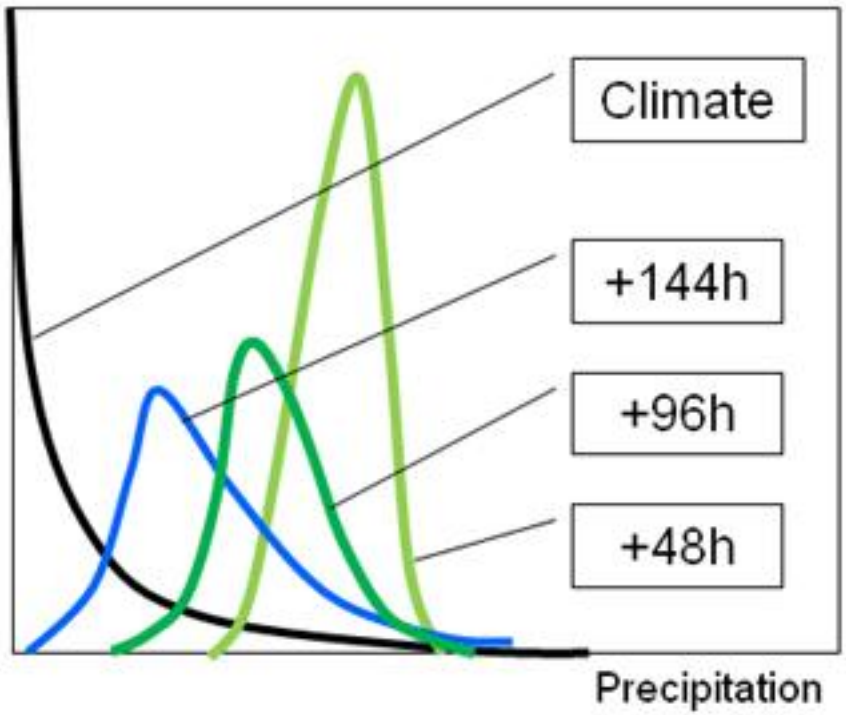
But what if you do have reforecasts but you don't have a long time series of observed/ analyzed data.

Can you leverage your reforecast to tell you something about how unusual today's weather forecast is?

ECMWF's Extreme Forecast Index does this.

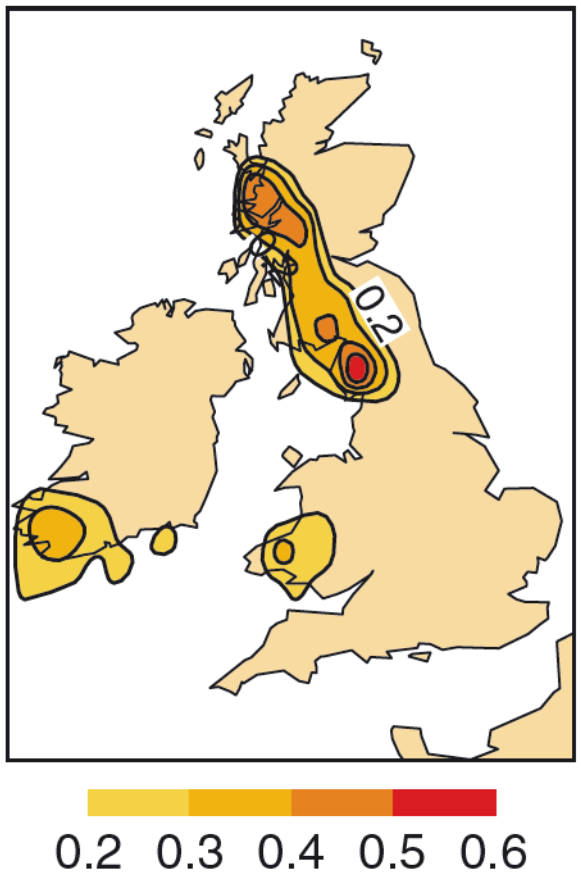
EFIs typically get more extreme in advance of a high-impact event





c/o ECMWF

EFI



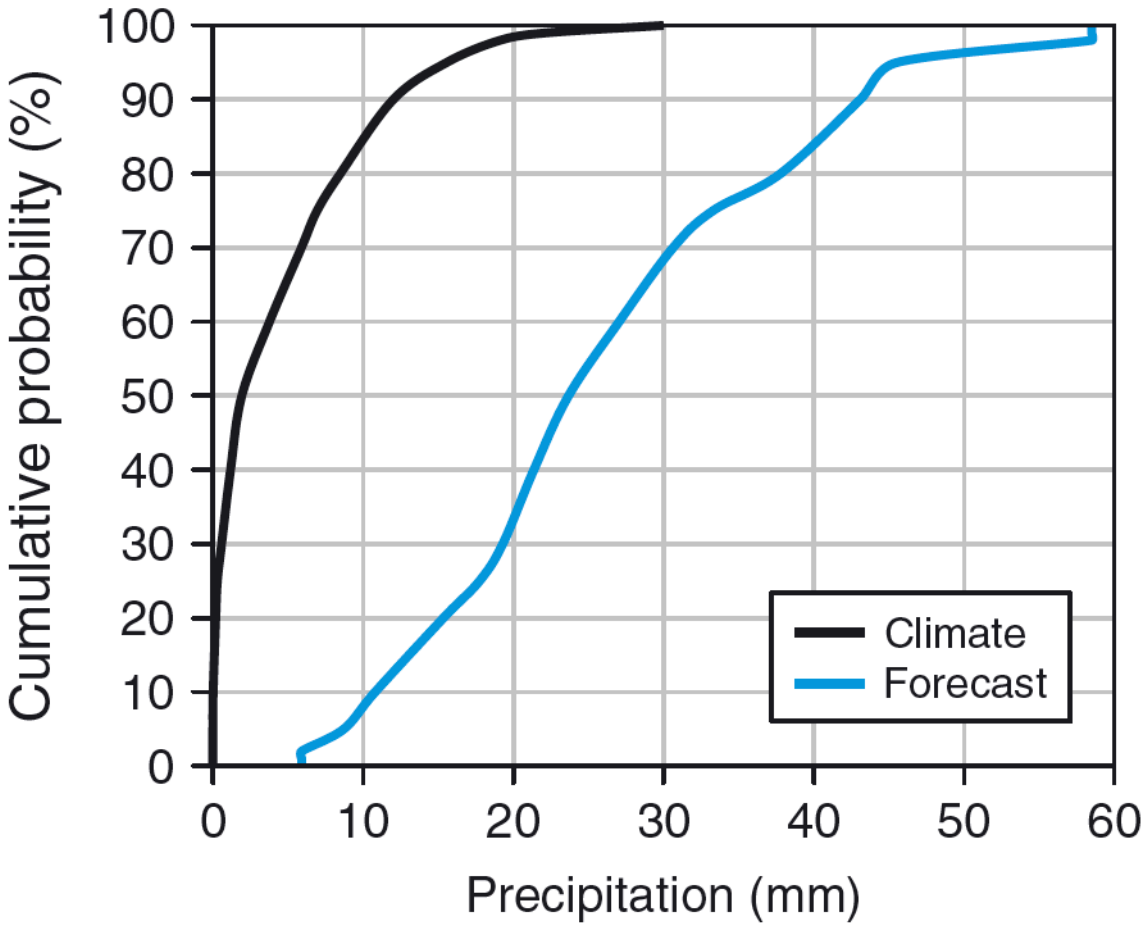
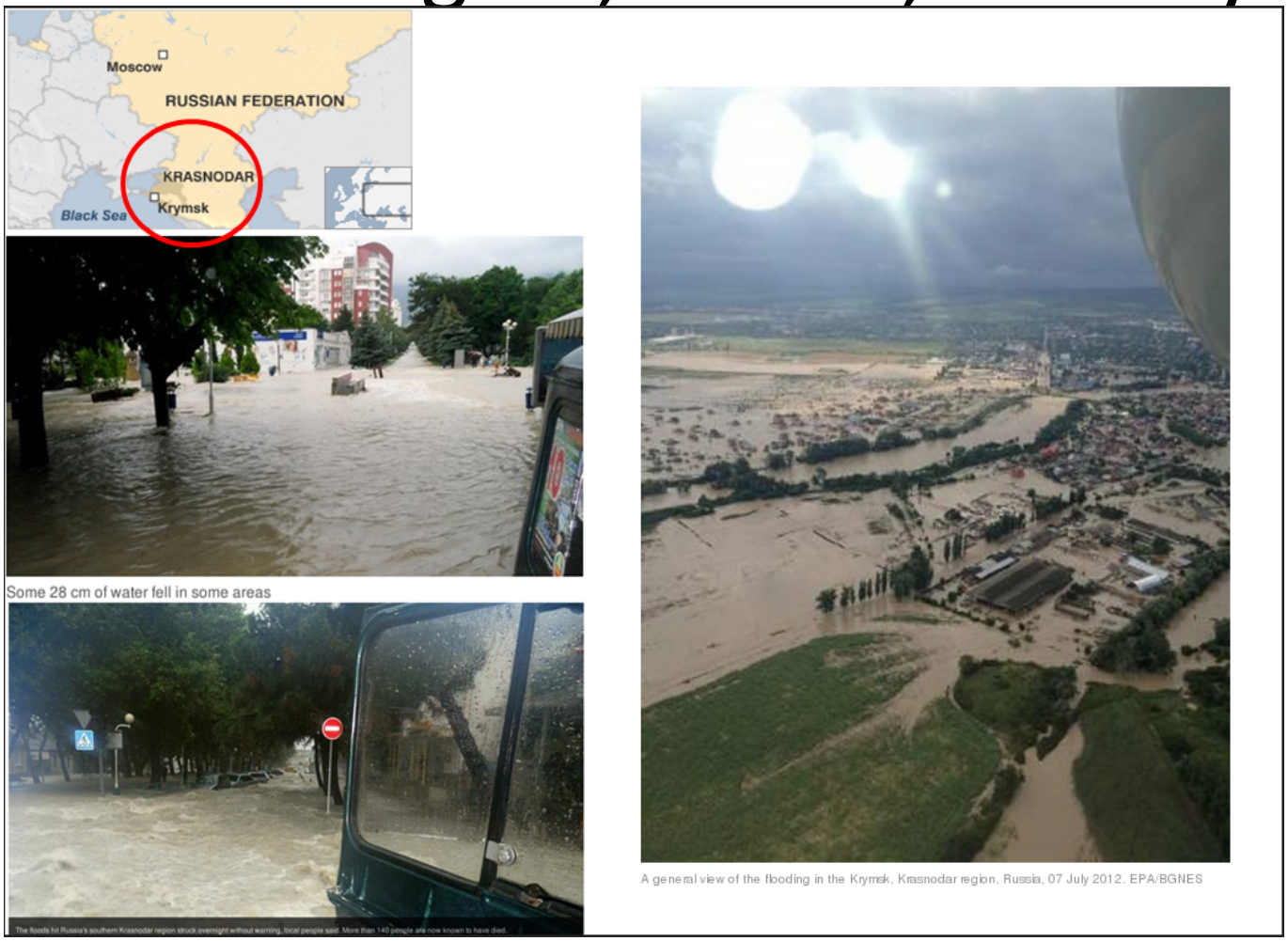


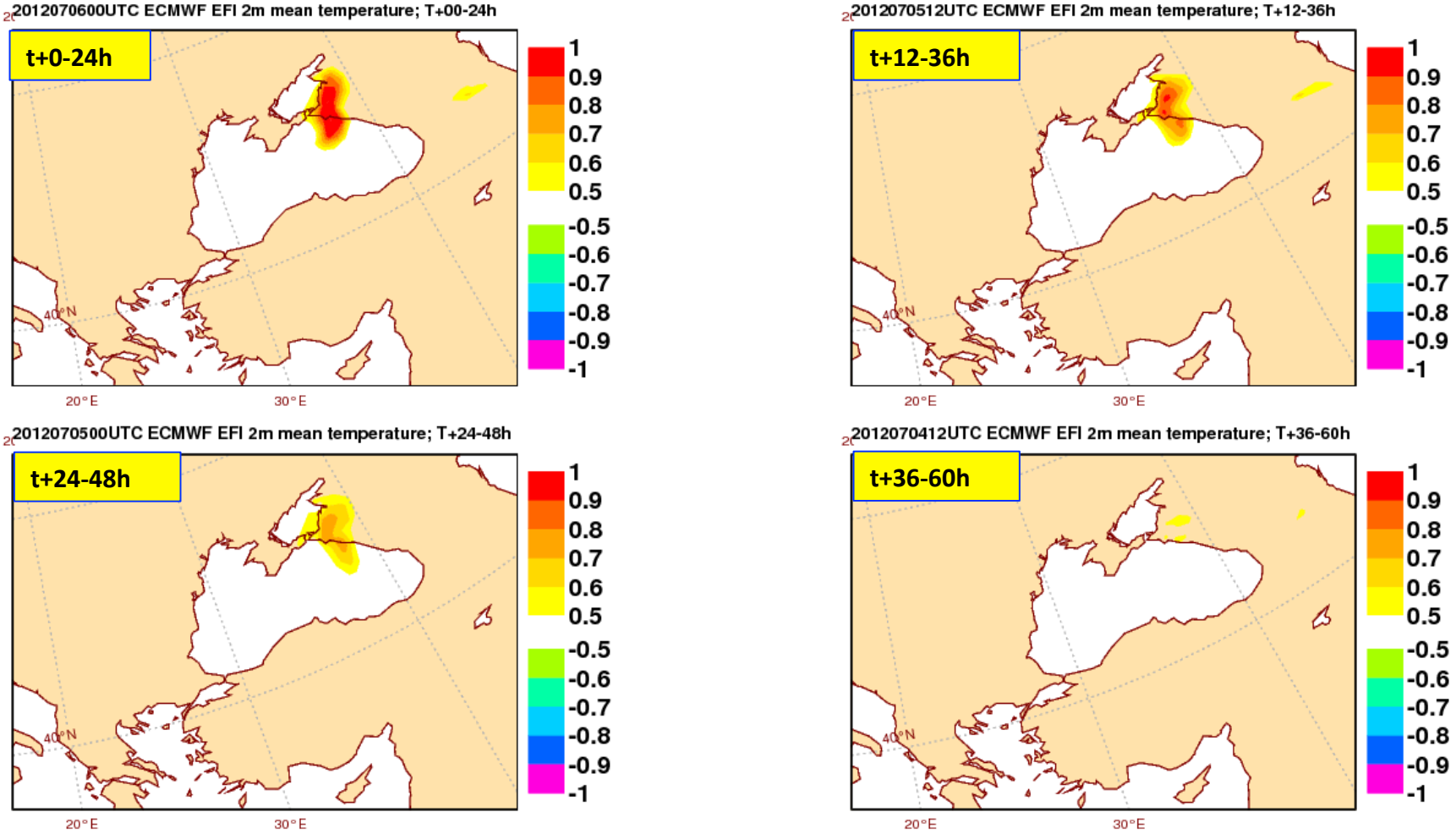
Figure 5. Floods in November 2009: EPS forecast from 00 UTC on 15 November. Left: the EPS forecast shows up to 50% probability for heavy rainfall (more than 25 millimetres in 24 hours) on 19 November. Right: model climate (black) and EPS forecast (blue) distribution of 24-hour rainfall for a grid point in Cumbria.

Krasnodar region, Russia, 6-7 July 2012



- Severe flash floods caused by torrential rain killed more than 140 people in Krasnodar region in the early hours of Saturday morning, 7 July 2012. Some 280 mm of rain fell in some areas according to the local authorities.

EFI for total precipitation



- Very strong signal of heavy precipitation on the day of the event. Some indications 2 days in advance.

EFI display combining wind and precipitation

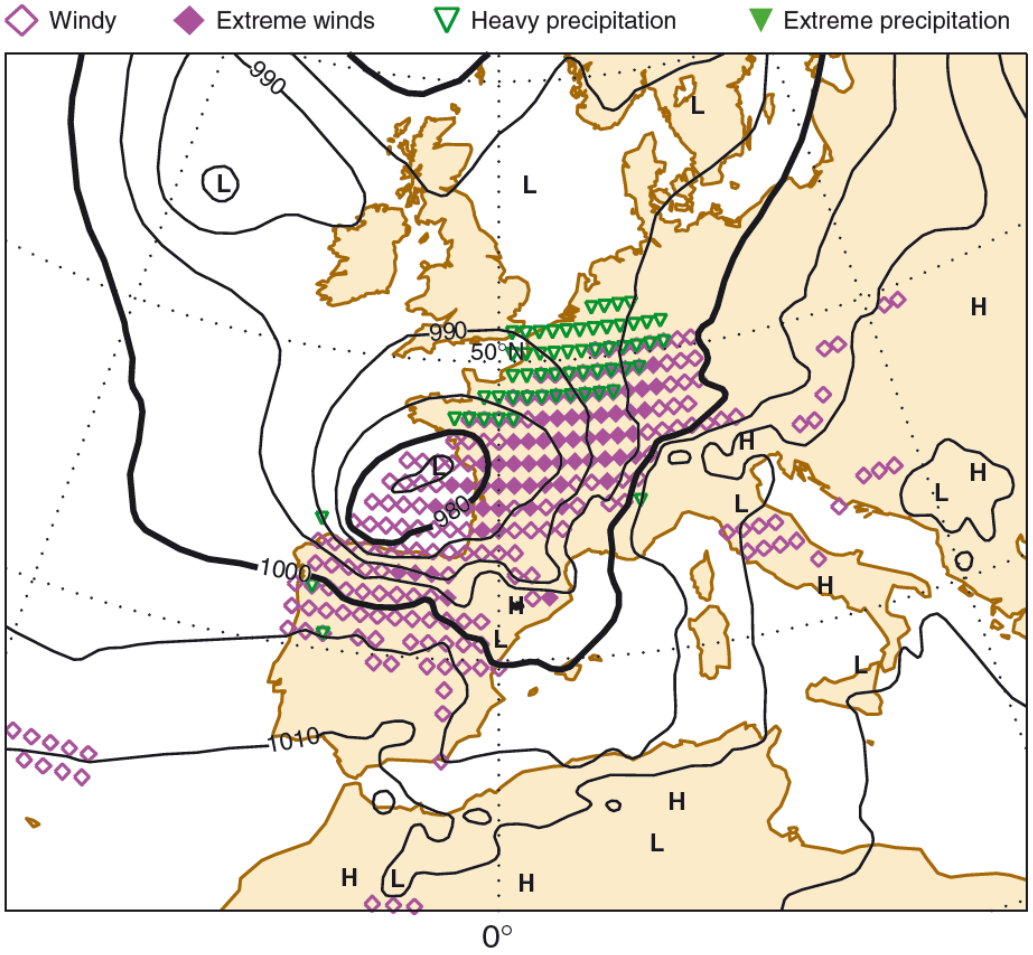


Figure 7. Early warning for winter storm Xynthia, February 2010: high-resolution deterministic model and EPS forecasts initialised at 00 UTC on 26 February. Contours show the sea-level pressure field for 00 UTC 28 February as forecast by the deterministic model. Coloured symbols show the Extreme Forecast Index (EFI) warnings of extreme winds (purple symbols) and heavy rainfall (green symbols) to occur during 28 February (00 UTC on 28 February to 00 UTC on 1 March). Filled-in symbols indicate greater risk of extreme events.

c/o David Richardson, ECMWF

Will your meteorological display system have the sorts of plots I'll show you here?

I don't know.

If you like these, push your weather services to make these graphics more readily available.

Conclusions

- Many ensemble display techniques out there.
- Understanding how ensembles work and their limitations can help you learn to use the ensemble guidance more productively.

Dendritic growth zone: depth of -12 to -18C layer